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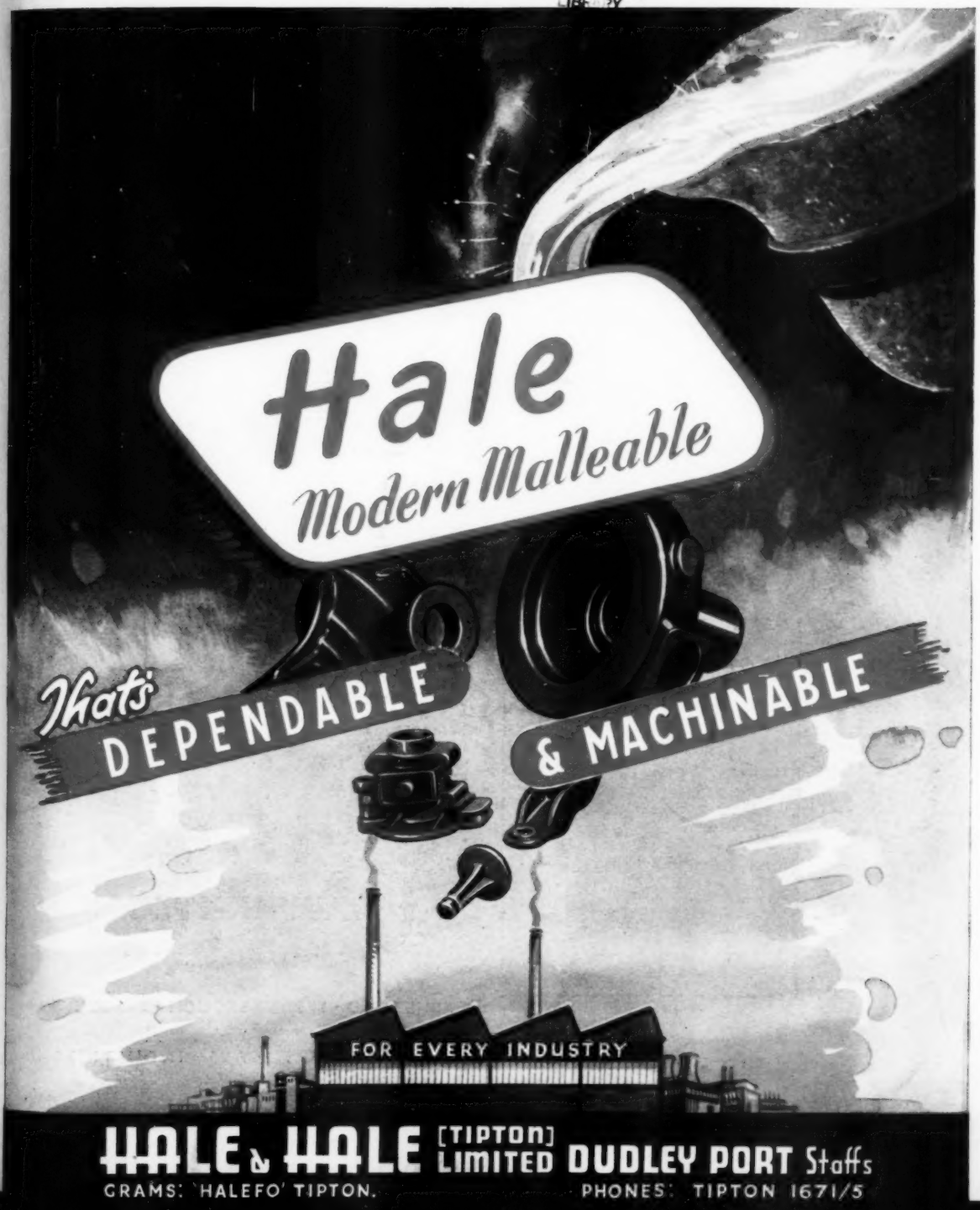

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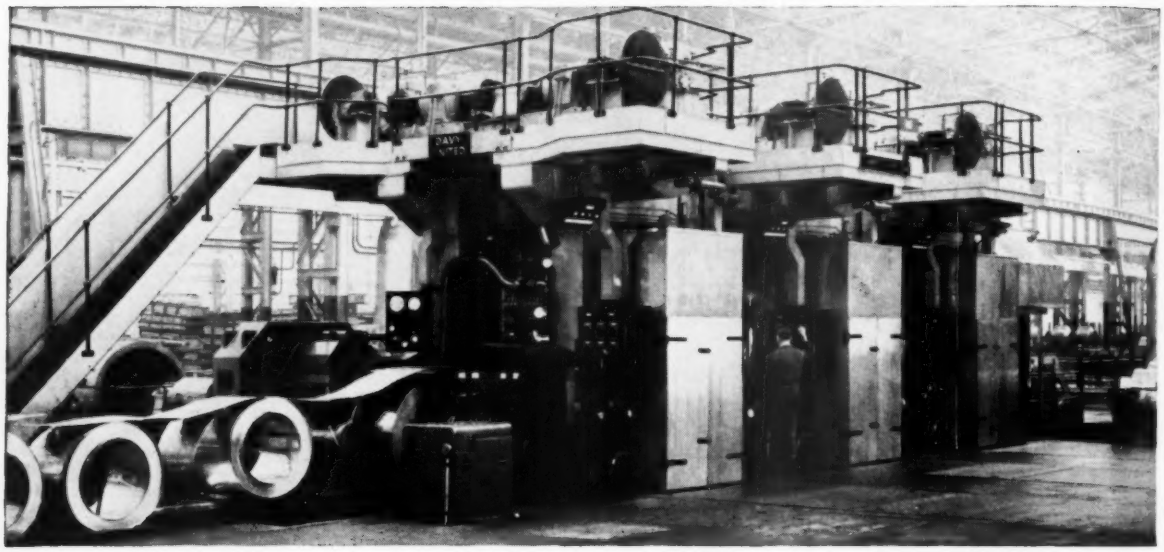

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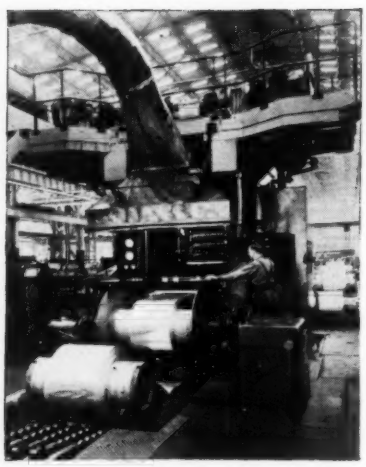

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THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

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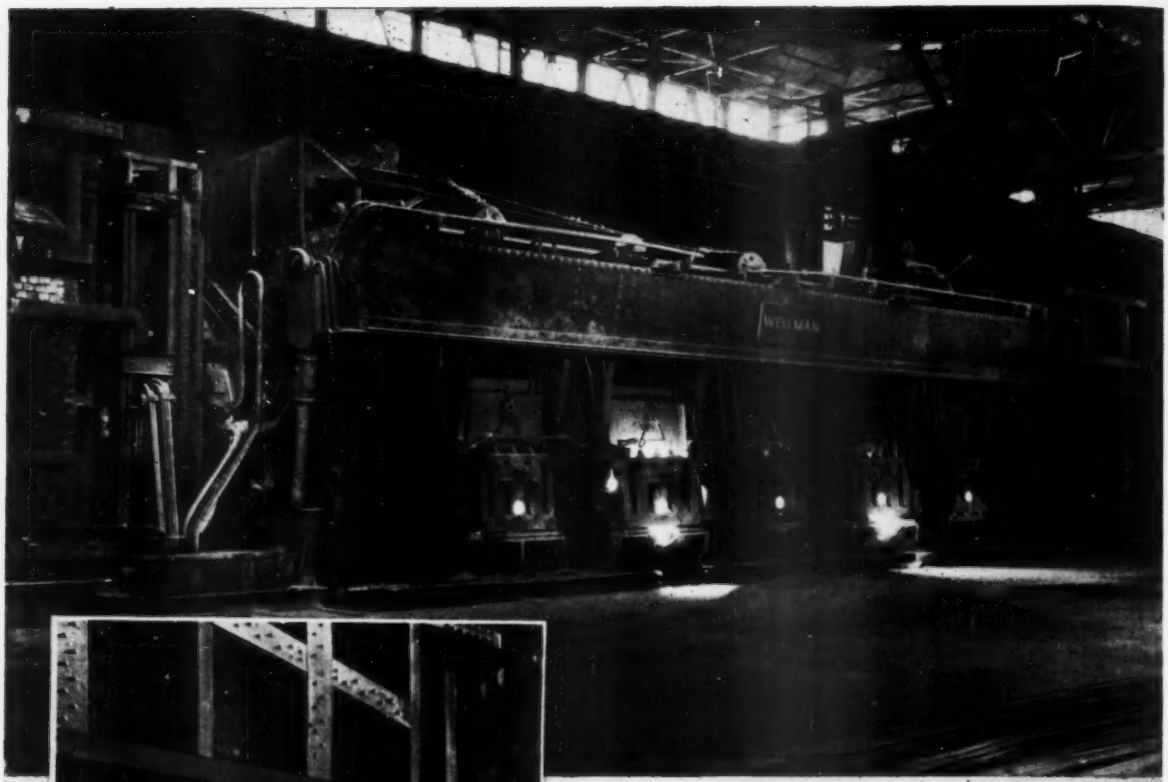

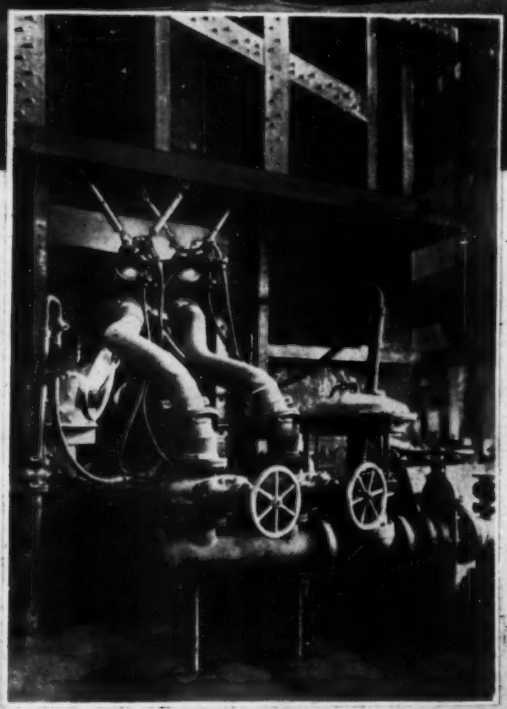

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THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

JULY, 1958 Vol. LVIII. No. 345

Wagons and Stars

AT the luncheon which followed the opening of the new research building of the Production Engineering Research Association at the beginning of last month, Lord Chandos spoke in general terms of research and development, pointing out that, industrially speaking, they are synonymous with imagination and its fulfilment. Lord Chandos then went on to discuss the immense acceleration in our powers to produce which has taken place since the beginning of the century, an achievement of which it is doubtful whether the layman has any conception. It has even been said by some thinkers that the solution of man's economic problem is within sight in (say) a hundred years. Within twenty years, man may have at his command an unlimited source of energy from a raw material costing nothing. The agricultural chemist too, not to be outdone, may have doubled the grass production of the country.

Progress is being made in these directions which is not immediately obvious to the man in the street. There can be few however, who have not come up against automation in one way or another, and to whom the electronic engineers boast that automation will make unnecessary the sweat and toil of production, will seem a fantasy. But without adequate "public relations" it may seem more like a threat than a promise—not a fantasy but a nightmare, with unemployment as a likely outcome. The advocates of automation, however, claim that the result of its application will be an improvement in the standing of the worker: he will be called upon to use more and more brainwork, and to work less and less with his muscles and his hands.

Whatever aspect of progress we may consider, research and development are the basis on which it is being and will be built. They are as necessary to our continued existence in this modern world as sun and rain are to the growth of sturdy and healthy crops. This is true of almost any country, but it is particularly true of those such as the United Kingdom, which are not highly endowed with raw materials. As Lord Chandos pointed out, if we had an oilfield bubbling up beneath the Home Counties it would be a great help, for at least its existence would be enable us to make a few mistakes without deadly consequences. Again, if we could find somewhere in the country a Roan Antelope, or a Nehanga, or a Sudbury, we could afford to be perhaps a little less energetic than we are over the sort of subjects with which the research associations and the research and development departments of our industrial units are concerned. The plain, unvarnished fact is, of course, that we have none of these things, and that we must live by our brains and by the sweat of our brows—until automation makes the latter unnecessary.

We have a certain amount of mineral resources, including coal, which seems to be exceedingly difficult to extract from mother earth. Even our coal reserves are limited in extent, and it is generally felt that the development of nuclear energy has come at a very opportune time. Of other minerals, iron ore is one of which we have comparatively large deposits, but these are not of very high quality, and it will always be necessary to import this material to maintain production of iron and steel at its present level; and the same is true of other materials. Furthermore, as we are unable to produce sufficient food for the size of our population, it follows that this also must be imported. It should be quite obvious, therefore, that the country must have as the basis for its prosperity the slogan, "Export or bust," for only in this way can we pay for the imports which are necessary for our survival as an industrial nation.

At this point we again encounter our twin stars of research and development, for unless we keep in the forefront of technical development, to enable us to produce goods of the best quality at the same, or lower prices than those of our competitors, it will be difficult to maintain our present high—and it is high in spite of all the grumbles about rising prices and heavy taxation—standard of living. These results can only be achieved if research and development are lively. To ensure this, there are two essential requirements. In the first place, industry must receive from the universities and technical colleges a sufficient supply of the right men, well-grounded in mathematics and science, if the huge sums which industry devotes to research and development are to be efficiently and fruitfully used.

To illustrate the second requirement, Lord Chandos referred to the old saying, "hitch your wagon to a star," which may be taken as meaning that man going about his daily life—driving, so to speak, his wagon across the veldt—should turn his eyes upwards towards the stars, and realise that he is more than a waggoner, more than a perishable being tied to the dust. Industrially speaking, however, it is, perhaps, more appropriate to turn the phrase round, and to say that one of our difficulties is to hitch our stars to a wagon.. Lord Chandos said he ran into the problem very early in his industrial life, when his company, engaged in mining, employed a brilliant chemist to look into some problems created by slime concentration. At the end of a year, with an ingratiating smile, the chemist told the metal company that he had been able to rearrange the molecular structure of natural rubber. This process is now a well-known feature of the world in which we live, but at the time it was rather an embarrassment than an exhilaration to a company engaged in mining, concentrating, smelting and refining metals. One cannot with advantage, confine research workers to those lines which are going to bring material benefits in a limited and defined field to the company which employs them, for in that way some of the most imaginative and constructive brains would be frustrated. On the other hand, stars must be hitched to wagons for at least some part of the day if ordered progress is to be made.

In the Birthday Honours List

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Continued on page 9

The Pack Carburising and Annealing of 4¼% Ni-Cr-Mo Case Hardening Steel

By C. Dawes

Joseph Lucas, Ltd., Birmingham

Various compounds have been used to carburise a 4¼% nickel-chromium-molybdenum steel, and the influence of these on the "as quenched" hardness, microstructure, carbon content and annealing characteristic of the carburised case is described. Recommendations are made for a carburising compound which will prevent the formation of heavy carbide networks and for a standard annealing treatment. This first section of the article is concerned with the carburising aspect.

PACK carburising and the subsequent heat treatment of plain low carbon steels by conventional methods was developed as an art on which factual data was accumulated long ago. With the introduction of the alloy case hardening steels, the same carburising compounds and annealing methods have been retained with very little modification.

Now these carburising compounds result in carbon concentrations in the case ranging upwards from 0·90%. Whilst such a carbon level is advisable with plain carbon steels, it is known that with the more heavily alloyed steels, especially the En 39B class, this high carbon is disadvantageous and leads to :

(1) The development of a massive globular carbide layer on the extreme outer edge of the case, the formation of which is accompanied by a serious depletion of the alloy content of the austenite ; this in turn leads to a raising of the M_s-M_f range of the outer region of the case. During quenching for hardening, therefore, transformation is completed first in this outer layer, the intermediate layer or middle zone (now having the lower M_s-M_f temperature range) being the last to transform. Thus the expansion which occurs when the latter transformation takes place, may build up sufficient stress to cause rupture of the surface layer which is already hard.

(2) The production of excess carbide in the form of cementite networks round the grain boundaries, which creates a problem with a component that is to be ground, since it tends to promote cracking during grinding operations.

(3) The retention of austenite on cooling from carburising, which complicates the annealing characteristic.

(4) The retention of austenite on quenching for hardening, giving low case hardness values.

With pack carburising, control of these high carbon concentrations cannot be obtained satisfactorily by varying the temperature or by diffusion techniques. For this reason, the effect of varying the composition of the compound, namely the amount and nature of the energising material, was investigated, and is considered in the first part of this article.

It is often necessary for production reasons to machine a component after carburising rather than to protect, by plating or other means, areas that are required to remain soft. Although plain low carbon carburising steels machine fairly readily in the "as carburised" condition, since both case and core have relatively low hardness values, this is not so with the high alloy carburising steels of the En 39B class, which, even after pack carburising and box cooling, have hardness values between 40 and 60 Rockwell C. This is due to the sluggish transformation characteristics of the high alloy steels, which, after carburising and relatively slow cooling, have a structure comprising the hard acicular constituents bainite and martensite in a matrix of austenite. The second part of this article deals with an investigation made to establish the shortest annealing cycle to give structures that will machine satisfactorily.

TABLE I.—DETAILS OF PRESENT DAY COMMERCIAL COMPOUNDS.

Compound No.	Type	Energiser Analysis
1	Hardwood Charcoal	9% $BaCO_3$, 3% $CaCO_3$, 2% Na_2CO_3
2	Hardwood Charcoal	5% Na_2CO_3
3	Coke and Charcoal	8% $BaCO_3$
4	Hardwood Charcoal	9% $BaCO_3$, 4% $CaCO_3$
5	Hardwood Charcoal	50% Bone Ash

PACK CARBURISING

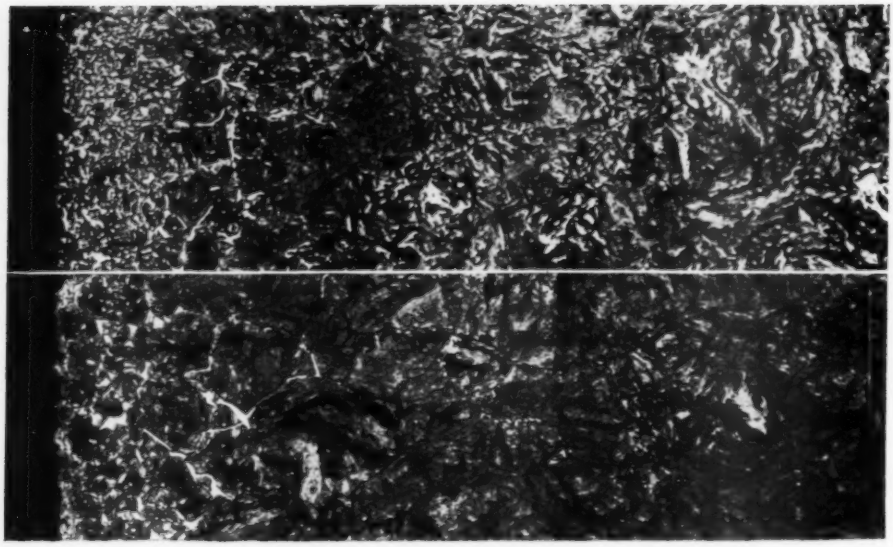
Present Day Carburising Media

There are two principal types of carburising compound on the market at present, the distinguishing feature being the method by which the energiser is added. One type usually referred to as "surface-coated," consists of charcoal, to the surface of which an energiser, usually barium carbonate, has been made to adhere, often being bonded with molasses. In the other type, usually called "impregnated", a water-soluble impregnated energiser is used and the charcoal is soaked in a solution of sodium or calcium carbonate.

The amount of energising material added to the charcoal appears to vary between 5 and 20%, although the majority of commercial compounds are still sold under trade names rather than to a specified composition. Some typical chemical compositions of compounds used today are given in Table I.

In carburising, a mixture of old and new compound is used ; the proportion of new varies with conditions and is usually between 5 and 10%, the purpose being to make up losses from dusting and burning.

Typical photomicrographs of En 39B specimens which were carburised for 16 hours at 900° C. with compounds



(*a*)

(*b*)

Fig. 1—Steel to En 39B, carburised for 16 hours at 900° C., using (a) 9% $BaCO_3$, 2% Na_2CO_3, 3% $CaCO_3$ compound, diluted 9 : 1; and (b) 5% Na_2CO_3 compound, diluted 9 : 1. × 250

1 and 2 (Table I), using a mixture of 9 parts old to 1 part new, are shown in Figs. 1*a* and 1*b*.

Experimental Work

Steel Specification

The main part of the investigation was confined to the carburising of a 4¼% nickel-chromium-molybdenum (En 39B–S 82) type of steel, but for interest, additional tests were made using plain carbon steel (En 32A–S 14).

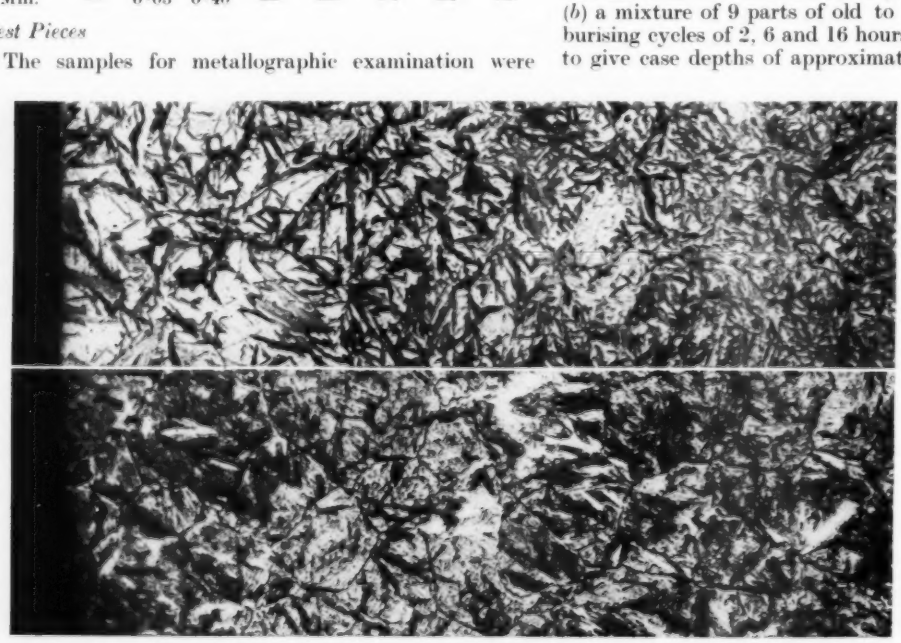
	C%	Si%	Mn%	S%	P%	Ni%	Cr%	Mo%
En 39B								
Max.	0·18	0·35	0·50	0·05	0·05	4·50	1·40	0·35
Min.	0·12	0·10	—	—	—	3·80	1·00	0·15
En 32A								
Max.	0·15	0·35	0·70	0·05	0·05	—	—	—
Min.	—	0·05	0·40	—	—	—	—	—

Test Pieces

The samples for metallographic examination were obtained by machining 1 in. diameter, 1 in. long test specimens from 1¼ in. diameter annealed rod. For carbon gradients, the En 39B samples were obtained in the form of 2½ in. diameter, 8 in. long machined tubes, with wall thickness of ¼ in., whereas the En 32 samples were obtained in the form of 1½ in. diameter machined bar which was cut into 8 in. long test specimens. The samples for case hardness gradients were obtained by machining ½-in. diameter, 3 in. long test specimens from ¾-in. diameter annealed rod.

Carburising Conditions

Details of the special compounds used in the investigation are given in Table II. Specimens for metallographic examination were carburised in (*a*) new compound, and (*b*) a mixture of 9 parts of old to 1 part of new. Carburising cycles of 2, 6 and 16 hours at 900° C. were used to give case depths of approximately 0·020, 0·040 and



(*a*)

(*b*)

Fig. 2—Steel to En 39B, carburised for 16 hours at 900° C., using 2% BaO compound diluted 9 : 1 (a) air cooled from the carburising temperature; (b) furnace cooled from the carburising temperature and double tempered. × 250

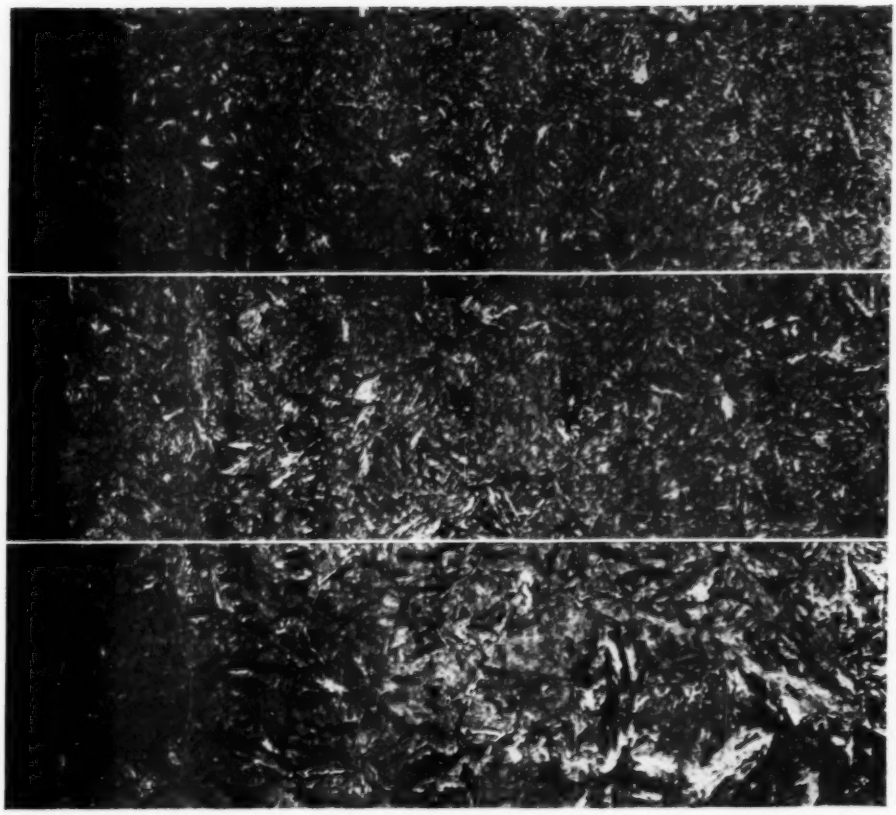


Fig. 3—Steel to En 39B, carburised at 900° C. with 1% Na_2CO_3 compound, diluted 9 : 1; (a) for 2 hours; (b) for 6 hours; (c) for 16 hours. × 250

0·060 in., respectively. The carbon and hardness gradients were limited to those tests which from micro examination seemed the most promising.

Method of Investigation

Metallographic Examination.—With carburised En 39B, it was difficult to distinguish the filaments of carbide and the massive globular carbide islands from the matrix of the white etching retained austenite (Fig. 2*a*). The specimens were, therefore, furnace cooled from carburising (in this instance approximately 100° C./hour) and then double tempered at 550° C. for three hours. This allowed the pro-eutectoid carbides to precipitate at the grain boundaries, and the double tempering treatment at 550° C. transformed the austenite retained on cooling from carburising into tempered martensite. Thus, all constituents except the carbides etched dark with nital (Fig. 2*b*).

With the En 32 samples, satisfactory structures for examination were readily achieved by box cooling in air from carburising. In addition, all the specimens were examined in the refined and hardened condition.

TABLE II.—COMPOUNDS USED IN THE INVESTIGATION.

Type	Energiser
Hardwood Charcoal—Water-Soluble Energiser	5% Sodium Carbonate
Hardwood Charcoal—Water-Soluble Energiser	1% Sodium Carbonate
Hardwood Charcoal—Water-Soluble Energiser	2% Barium Oxide
Hardwood Charcoal Molasses-Bonded Energiser	2½% Barium Carbonate
Hardwood Charcoal	No Energiser

Carbon Gradients.—It was found necessary to soften the alloy steel specimens for machining. This was achieved by tempering for 3 hours at 700° C., followed by 3 hours at 650° C. Increments of 0·0025 in. were then machined from each specimen for chemical analysis.

Hardness Gradients.—The En 39B test specimens were refined and hardened by heating to 880° C. and oil quenching, followed by heating to 760° C. and oil quenching. The plain carbon test specimens were refined and hardened by heating to 900° C. and oil quenching, followed by heating to 780° C. and water quenching. The specimens were then re-centred and taper ground to an angle of 2°. Vickers hardness checks using a 2½ kg. load were then made at approximately 0·1 in. intervals along the taper. In addition, the alloy steel specimens were sub-zero treated at −60° C., and hardness checks were repeated at approximately the same positions along the taper.

Case Depths.—The hardenability of En 39B is sufficient to produce a martensitic case and core, even when slowly cooled from carburising; the problem, therefore, arose of how to estimate the depth of the carburised case. However, it has been found that with this particular steel the isothermal transformation to pearlite in the case is completed before transformation in the core is very much advanced. Thus, it is possible to show a demarcation between the case and core by austenitising and then quenching to and holding for sufficient time at a sub-critical temperature to transform the case only, the core being transformed to martensite on cooling.

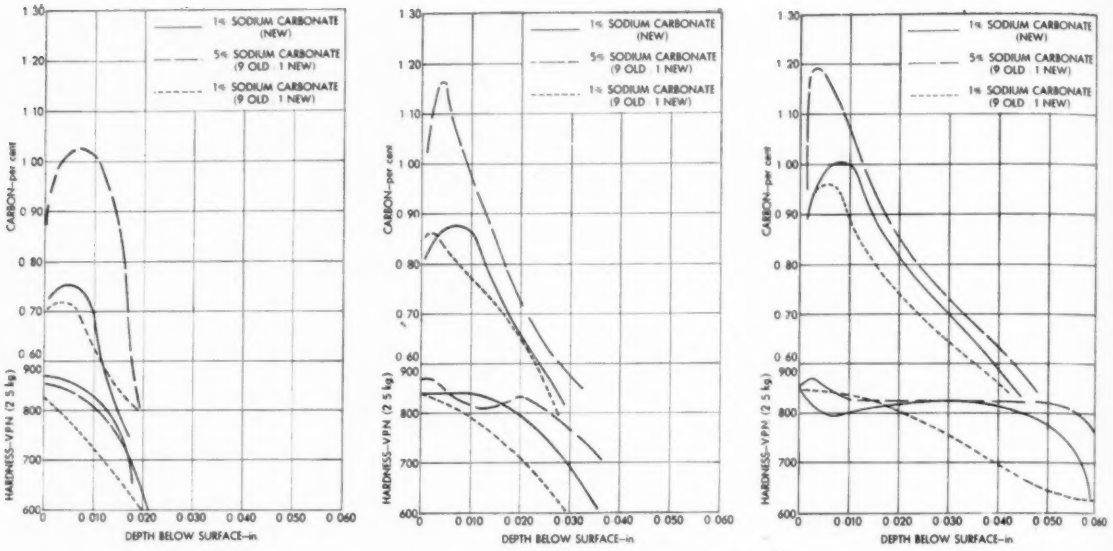


Fig. 4—Carbon and hardness gradients in steel to En 39B, for various case depths : (a) carburised 2 hours at 900° C.; (b) carburised 6 hours at 900° C. ; (c) carburised 16 hours at 900° C. All specimens were heated to 760° C., oil quenched, and sub-zero treated at −60° C.

The alloy steel specimens after carburising were therefore packed in boxes with clean cast iron borings, austenitised at 750° C., given a half hour soak at temperature, and then transferred to a furnace at 580° C. and held for 4 hours. The boxes were then removed from the furnace and air cooled to room temperature.

With the plain carbon specimens, the case depths were measured on both hardened and " as carburised " micro specimens. All the samples were etched in a nital-picral solution, and the case depth was measured with a Brinell microscope.

Abrasion Test.—Past experience has shown that compounds which have their energising material surface-coated onto the charcoal particles show a serious loss of carbon activity with continual use. It was considered necessary to develop a form of abrasion test to investigate this phenomenon ; particularly as at this stage it was suspected that the loss probably occurred by abrasive action. Although such a test could only be of an empirical nature, it would allow a comparison to be made between the different compounds. The following procedure was devised :—

(1) 500 g. of compound was sized into coarse and dust, using a square mesh sieve of $\frac{3}{64}$ in. spacing, the products being weighed and analysed for the percentage of energising material.

(2) The coarse compound was then placed in a carburising box which was subsequently heated to 900° C. for 3 hours, following which it was removed from the furnace and air cooled.

(3) The compound was re-sieved to separate the coarse compound from the dust, and again weighed and analysed.

(4) The remaining coarse compound was then placed in the cylindrical drum (7 in. diameter × 7 in. long) of a tumbler machine, together with approximately 200 g. of rumbling stars (50% by weight of the compound). The drum was then rotated at approximately 17 r.p.m. for a total time of 1 hour.

(5) The sample was re-sieved and the final products again weighed and analysed.

Results

Metallographic Examination

(a) En 39B

The 5% sodium carbonate compound, even when diluted with 9 parts of old to 1 part of new, gives a massive globular carbide layer at the surface of the carburised case (Fig. 1*b*). With new 2% barium oxide and $2\frac{1}{2}$% barium carbonate compounds, excess carbide is present both as network and as isolated islands near the surface. When diluted with 9 parts of old to 1 part of new, the 2% barium oxide compound still shows heavy carbide networks (Fig. 2*b*), whereas the $2\frac{1}{2}$% barium carbonate gives only very faint networks. With new 1% sodium carbonate compound, excess carbide is present only as networks, and when diluted with 9 parts of old to 1 part of new—except for faint networks at the corners—virtually no excess carbide is shown (Fig. 3). Charcoal shows very satisfactory structures in so far as no excess carbide is observed ; however, it is difficult to estimate the carbon content of the martensite by metallographic examination alone, and thus it is hard to say whether the carbon is adequate for full hardening to be obtained.

(b) En 32

The 5% sodium carbonate compound diluted with 9 parts of old to 1 part of new gives hypereutectoid structures, whereas when the lowly energised compounds, i.e., the 2% barium oxide, $2\frac{1}{2}$% barium carbonate and 1% sodium carbonate are used, the carburised case is only just eutectoid. A hypoeutectoid case is obtained when a $2\frac{1}{2}$% barium carbonate compound diluted with

9 parts of old to 1 part of new is used for carburising. With charcoal, very low carbon cases are obtained.

Carbon Gradients

(*a*) *En* 39*B* (Fig. 4)

The 5% sodium carbonate compound, diluted with 9 parts of old to 1 part of new, gives surface carbon levels ranging from 1·0% after 2 hours carburising, to 1·20% after 16 hours carburising. The 1% sodium carbonate compound gives a surface carbon content ranging from 0·75% after 2 hours carburising to 1·0% after 16 hours treatment. When this compound is diluted with 9 parts of old to 1 part of new, the surface carbon level ranges from 0·72% after 2 hours carburising to 0·96% after 16 hours carburising.

(*b*) *En* 32

With the 5% sodium carbonate compound, diluted with 4 parts of old to 1 part of new, surface carbon levels ranging from 1·0% after 2 hours carburising to 1·10% after 16 hours are obtained; whereas with new 1% sodium carbonate, the surface carbon ranges from 0·90% after 2 hours carburising to 1·0% after the 16 hour cycle.

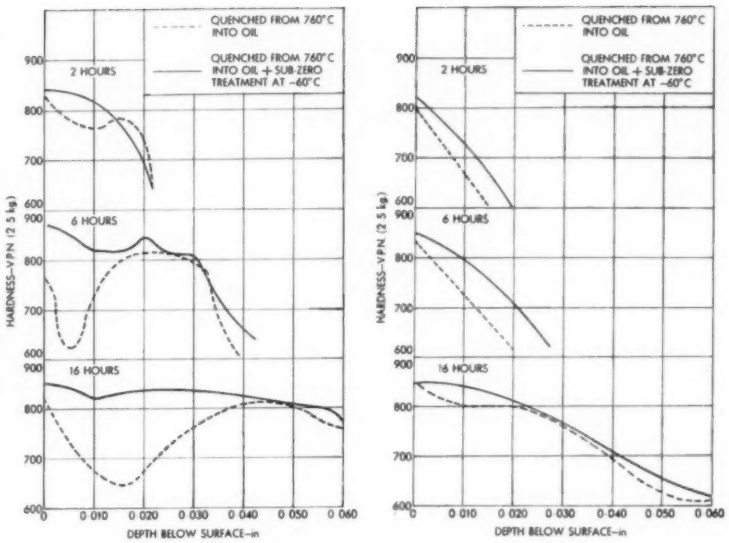

QUENCHED FROM 760°C INTO OIL
QUENCHED FROM 760°C INTO OIL + SUB-ZERO TREATMENT AT −60°C
2 HOURS
6 HOURS
16 HOURS
HARDNESS—V.P.N. (2·5 kg)
DEPTH BELOW SURFACE—in
0 010 0 020 0 030 0 040 0 050 0 060
(a)
(b)

Fig. 5—Hardness gradients with strong and weak compounds in steel to En 39B: (a) carburised 900° C. in 5% Na_2CO_3, diluted 9 : 1; (b) carburised 900° C. in 1% Na_2CO_3 diluted 9 : 1.

Hardness Gradients

(*a*) *En* 39*B* (Figs. 4 and 5)

Little difference is found between the surface hardness values obtained after hardening and sub-zero treating on samples carburised in the various compounds. With the more highly energised compounds, however, the depth of hard zone is increased slightly, but the hardness values then fall off rather abruptly. On the other hand, with the lowly energised compounds, there is a gradual decline in hardness values from the surface of the case to the core (Fig. 4).

The difference between hardness values of "quenched" and "quenched and sub-zero treated" specimens carburised with the diluted highly energised compound, i.e., diluted 5% sodium carbonate, is illustrated in Fig. 5*a*. The hardness values "as quenched" fall off rapidly immediately below the surface due to the retention of austenite. On sub-zero treatment this breaks down to martensite, with consequent increase in hardness. With the lowly energised compound, i.e., diluted 1% sodium carbonate, (Fig. 5*b*) the difference in hardness values between "as quenched" and "as quenched and sub-zero treated" is quite small.

The results obtained with charcoal are not consistent for carburising time of 6 hours or more.

(*b*) *En* 32

Hardness values of about 800/820 V.P.N. are obtained on specimens carburised in new lowly energised compound (1% sodium carbonate), whereas 900 V.P.N. is obtained with a diluted highly energised compound (9 of old to 1 of new 5% sodium carbonate).

Case Depths

(*a*) *En* 39*B*

Little variation in case depth occurs when different compounds are used. The results obtained with charcoal were indefinite.

(*b*) *En* 32

With the lowly energised compounds, penetration rates are lowered markedly by the degree of dilution, for example with new 1% sodium carbonate, a case depth of 0·040 in. is obtained in 6 hours, whereas with diluted (9 of old to 1 of new) 1% sodium carbonate, the same time gave a case depth of only 0·027 in. It was noted, however, that the penetration rate of *new* 1% sodium carbonate, compared favourable with *diluted* 5% sodium carbonate compound.

TABLE III.—ABRASION TEST RESULTS.

Compound	Type	Compound as Received					After 3 hours Treatment at 900° C.					After Barrelling for 1 hour at 17 r.p.m.				
		Weight of Sample Tested (g.)	Weight of Coarse Compound (g.)	Weight of Dust (g.)	Energiser in Coarse Compound (%)	Energiser in Dust (%)	Weight of Coarse Compound (g.)	Weight of Coarse Compound After Treatment (g.)	Weight of Dust After Treatment (g.)	Energiser in Coarse Compound (%)	Energiser in Dust (%)	Weight of Coarse Compound Tested (g.)	Weight of Coarse Compound After Barrelling (g.)	Weight of Dust After Barrelling (g.)	Energiser in Coarse Compound (%)	Energiser in Dust (%)
2½% $BaCO_3$	Molasses-Bonded	500	483	17	1·33	17·40	483	259	2	0·26	18·50	259	255	4	0·20	4·75
2% BaO	Water-Soluble	500	490	10	1·67	4·14	490	342	2	1·54	1·96	342	336	6	1·50	1·86
1% Na_2CO_3	Water-Soluble	500	489	11	0·72	1·91	489	361	1	0·67	0·84	361	357	4	0·74	1·12

Abrasion Tests (Table III)

A large proportion of the energising material was found in the dust of the " as received " compound, and in the dust after blank carburising. The loss caused through barrelling (which simulates rough handling, mechanical screening, abrasion, etc.) is very small.

Analytical results show that the surface-bonded (molasses) barium carbonate compound suffers a high energiser loss on carburising, i.e., 1·31% to 0·26% whereas the impregnated water-soluble compounds (sodium carbonate and barium oxide) retain their energiser strength reasonably well.

Discussion

Influence of Compound on Surface Carbon Content

In the carburising process, it is known that the carburising gas, whether produced from a solid, liquid, or atmosphere, breaks down at the steel surface to give atomic carbon which is then absorbed into the steel. This absorbed carbon then migrates by normal solid diffusion: hence the rate of carburisation is a function of (*a*) the carbon diffusion coefficient of the steel, and (*b*) the carbon potential at the surface of the steel.

Now the diffusion coefficient for a particular steel is a function of temperature, whilst the carbon potential at the surface is a function of the activity of the carburising compound. Thus, it is clear that if the carbon activity of a compound is such that carbon is supplied to the surface of the steel more quickly than it can diffuse away, then the surface layers will soon become saturated with carbon.

The excess cementite in carburised plain carbon steel is formed by precipitation during cooling, but the total carbon content at any point in the case can never exceed the saturation value for the carburising temperature, i.e., the A_{cm} composition. On the other hand, with the En 39B class of steel carburised in a high carbon activity —i.e., 5% sodium carbonate compound—a surface zone of globular alloy carbides is *formed at the carburising temperature*.

From what has already been said in the introduction, these globular carbides are clearly undesirable. Tests have shown, however, that saturation of the surface and consequent formation of these carbides is easily avoided by using a carburising medium of such low carbon activity that the carbon content at the surface may not reach the carbide saturation point.

When carburising mild steel which has (*a*) a carbon diffusion coefficient and (*b*) a eutectoid composition, both much higher than that of the alloy steel, then the concentration of carbon obtained in the case when carburising with weak compounds will be below the maximum for saturation. To ensure satisfactory carburising with this steel, therefore, it is necessary to use a compound of higher activity, such as a new lowly energised compound or diluted highly energised compounds.

Influence of Compound on Case Hardness Values After Carburising and Hardening

Studying the influence of carburising compounds and *ipso facto* the carbon concentration of En 39B, it will be obvious that vastly different case hardness values will be obtained when carburised surfaces with 0·70% carbon and 1·0% carbon, respectively, are hardened (Fig. 5*a* and 5*b*), since the retention of austenite increases with increasing carbon content.

Sub-zero treatment will break down this retained austenite, but it has already been pointed out that this may lead to rupture of the surface due to internal stresses. Therefore, the carbon content should not exceed the eutectoid level, in fact slightly hypoeutectoid cases are preferable—low enough to bring the M_f up to room temperature, and thereby minimise the retention of austenite. Of course, the carbon content must still be sufficient to ensure adequate hardness.

If a strong compound is used to carburise plain carbon steel, there is little likelihood of forming retained austenite in the case on quenching, despite the fact that the case will have a high carbon level.

When a weak compound is used to carburise plain carbon steel, the carbon content of the case will be satisfactory at the carburising temperature. It is likely, however, that the slight decarburisation which occurs on cooling will reduce the carbon content at the surface sufficiently to cause low case hardness values to be obtained on subsequent quenching.

Therefore, the established practice of forming a slightly hypereutectoid case when carburising mild steel is necessary in order to compensate for the slight decarburisation which occurs on cooling. Any small excess carbon is easily taken into solution during heating for hardening and, therefore, causes no adverse effects.

Nature of Compound

Since the performance and economy of a given compound depends so much on the retention of the energiser on the charcoal, it must be emphasised that the method of keeping the energising material in contact with the charcoal is of the greatest importance.

A careful study (Table III) reveals that compounds which have been energised with water-soluble materials such as sodium carbonate and barium oxide are better than the surface-bonded compounds. The advantage of these water-soluble energisers is that it is possible to deposit the chemical all through the pores of charcoal by soaking the charcoal in a sodium carbonate or barium oxide solution. Such a compound does not yield much free chemical when abraded.

Because of this, extremely severe usage can be given to water-soluble energised types of carburising compound before the carburising action suffers any substantial deterioration, and an addition of 10% new compound is sufficient to restore used compound to its original activity.

On the other hand, with surface-bonded compounds (molasses-bonded barium carbonate) severe loss of energiser occurs, since the structure of the charred binder is frequently weak. After a carburising treatment, therefore, practically all of the coated energiser is removed in the form of dust, thus leaving virtually pure charcoal, which is useless for further carburising treatments.

Conclusions

With a 4¼% nickel-chromium-molybdenum steel, it has been found that a 1% sodium carbonate or a 2½% barium carbonate compound give less excess carbide than the more highly energised compounds, and when used as a mixture of 9 parts of old to 1 part of new, they are satisfactory media for carburising. However, with compounds having low energiser contents, it is essential that the chemical should be adequately bonded to the charcoal to avoid loss under production conditions; this is only ensured by using water-soluble energisers.

With plain carbon steel, satisfactory carbon concentration and hardness values are obtained with new 1% sodium carbonate compound, but with a diluted compound low carbon cases are produced with the shorter carburising cycles. Therefore, when carburising mild steel with a 1% sodium carbonate compound it is necessary to use *new compound*. However, the use of new compound in this manner is wasteful unless alloy steel components are being carburised in the same shop. For these reasons, preference is given to a 5% sodium carbonate compound for carburising plain carbon steels, and diluted in the ratio of 4 parts of old to 1 part of new this gives a case which is definitely hypereutectoid, with satisfactory "as quenched" microstructures and hardness values. There would appear to be no advantage in using a compound with more than 5% energising material.

Commemorative Aluminium Medallion

THE Canadian British Aluminium Co., a subsidiary of The British Aluminium Co., Ltd., formed in partnership with the Quebec North Shore Paper Co., have issued a medallion to commemorate the first production of aluminium ingot at their Baie Comeau smelter. Less than 20 months after work commenced on the site, the first metal was poured there in December, 1957. These first ingots were sent to this country, and from them the sheet for the medallions was rolled at the Milton, Staffs., works of British Aluminium.

The medallion was designed by the Design Research Unit and produced by J. R. Gaunt & Son Ltd., of Birmingham. It was distributed to guests, employees and members of companies associated with the construction of the smelter on the occasion of the Official Opening by Mr. du Plessis, Premier of Quebec, on June 14th, 1958. The obverse of the medallion records in French the fact that it was produced from the first ingots from the smelter. The design of the reverse represents the essential features of the country in which the smelter is situated—rock, trees and water—and the conversion of the water into power for aluminium production is symbolised by a pylon.

Formation of Croda Belge

THE formation of a new company called Croda Belge, is announced by Croda, Ltd., of Goole. President of the new company, whose head office is at Verviers, the Bradford of Belgium, is MR. F. A. S. WOOD, 31 year-old managing director of the Croda organization, which already has associate companies in the U.S. and Italy. The managing director is MR. WERNER DAVELOOSE, a Flemish industrialist. Among other things, the new company will manufacture lanolin and use it to make the anti-corrosive compounds which have been so successful in the U.K.

Canada-Norway Barter Deal

CANADA and Norway have agreed upon a £71 million aluminium deal whereby over a 20-year period Canada will barter 3,700,000 tons of alumina to two Norwegian owned smelters in return for aluminium ingots. This deal is reported by Barclays Bank D.C.O. from Jamaica where, it says, production of alumina will be stepped up to meet the terms of the deal. Canada has substantial bauxite interests in Jamaica.

In the Birthday Honours List

(*continued from page 2*)

I.S.O.

L. J. EDGCOMBE, Chief Experimental Officer, Department of Scientific and Industrial Research.

B.E.M.

W. H. BUTLER, Apprentice Instructor, Supermarine Works, Vickers-Armstrongs (Aircraft), Ltd.
W. CAMBRIDGE, Chargehand Moulder, Ardeer Foundry Co., Ltd.
T. A. CHARLESWORTH, Works Manager, Abrafract, Ltd.
A. W. P. DAVY, Laboratory Worker A., Atomic Weapons Research Establishment.
W. G. ELLIOTT, Foreman-in-Charge Cranes, Workington Iron and Steel Co. (The United Steel Companies, Ltd.)
E. F. FOREMAN, Foreman, Research Laboratories, General Electric Co., Ltd. (Chipperfield).
W. U. KERRISON, Fitting Shop Foreman, North Eastern Marine Engineering Co., Ltd.
J. MCCANNAH, Chargehand Mechanical Fitter, Ferranti, Ltd.
C. MANLEY, Production Foreman, Edward Curran Engineering, Ltd.
F. W. MARKS, Senior Foreman, Hadfields, Ltd.
C. I. MURRAY, Apprentice Instructor, Imperial Chemical Industries, Ltd. (Redcar).
H. NOBLE, Foreman, J. Blakeborough and Sons, Ltd.
J. H. OATES, Honorary Collector, Pulsometer Engineering Co., Savings Group.
A. PARLIN, Section Leader (Draughtsman), Worthington Simpson, Ltd.
A. WATT, Civil Defence Officer, Bruce Peebles and Co., Ltd.
F. W. WITTON, Assistant (Scientific), Royal Mint.
F. R. WOODWARD, Research and Development (Special) Inspector, Royal Aircraft Establishment, Ministry of Supply (Blackwater).
W. A. WRIGHT, Manager (No. 7 Works), Punched Card Factory, Powers-Samas Accounting Machines, Ltd.

PERA Expansion

New Laboratories Officially Opened by Lord Chandos

The exterior of PERA's new research workshops and laboratories.

FOR ten years, the research facilities of the Production Engineering Research Association of Great Britain—more easily referred to as PERA—were housed in temporary auxiliary buildings, but permanent development of the 30-acre site is in progress, and the first part of the programme has been completed with the construction of the new workshops and laboratories opened last month by Lord Chandos.

New Building

The new building, which has been erected at a cost of £250,000, has a floor area of 45,000 sq. ft., and houses equipment, etc., worth about half a million pounds. The main workshops, in which the major part of the Association's researches into production techniques are carried out, have a floor area of about 20,000 sq. ft. The approximate floor areas of the other principal laboratories are as follows :

Machine tool laboratory	1,150 sq. ft.
Metrology laboratory	3,200 sq. ft.
Metallurgy laboratories	4,400 sq. ft. (1,300 sq. ft. for metallography and 3,100 sq. ft. for chemical analysis).
Electronics laboratory	600 sq. ft.
Radioactive laboratory	900 sq. ft.

The total floor area of drawing offices, administrative offices, etc., is 5,000 sq. ft.

Machines installed in the vibration section are isolated from the rest of the building to eliminate the effects of vibration from other machines. The floor of the metrology department has also been specially constructed to reduce the risk of vibration from the workshop. It consists of a conventional concrete foundation covered by a fibre-glass blanket approximately 1 in. thick, which is in turn covered by approximately 1 in. of concrete and a wood block floor. The floor is isolated from the walls by continuing the fibre-glass blanket round the edges of the floor. To reduce further the possibility of vibration, all benches and equipment are free standing, that is, they are not connected to the wall.

Research Activities

Nearly 100 major researches have been completed or are in progress. These include investigations of cutting fluids, blanking, piercing, bending, deep drawing, tapping, grinding, cold extrusion, de-burring, surface finish, centre lathes, friction, thread rolling, milling machines, vibration, lubrication, rolling bearings, drilling machines, finish blanking. In addition, approximately 1,200 practical investigations into specific problems have been carried out on behalf of particular firms. These include the cold extrusion of aluminium and steel components ; the performance of ceramic cutting tools ; machining of stainless steels, Nimonic alloys and titanium ; finish blanking of high tensile steels ; vibration of machine tools and other production equipment ; grinding of cutting tools ; metallurgical aspects of cutting tools and punches ; etc.

The 640 companies served by the Association make a wide variety of products ranging from domestic utensils and agricultural equipment to gas turbines and precision instruments. Moreover, the scale of manufacture ranges from one-off orders to the mass production of very large quantities. Despite the diversity of the production activities of member firms, the manufacturing techniques used have many features in common. Thus, the Association deals with the problems in groups such as metal cutting, presswork, machine tools, surface finish, automation, metal forming, etc.

Metal Cutting Research

The extent of research necessary to secure authoritative data for application in workshops may be judged from the fact that in one of PERA's tapping investigations, for example, approximately 300,000 holes were tapped, and in addition 10,000 tap measurements were made.

Similar principles underlie research into various machining techniques. They include accurate measurement of cutting forces, tool shape, tool life, surface finish, etc. ; close control of identifiable factors ; and systematic variation of selected factors of interest. Whenever practicable, control of the experimental variable is based on direct quantitative measurement. The range of special equipment developed by PERA for ensuring the uniformity of important geometrical features of cutting tools, for example, includes the lathe tool grinding attachment, tool angle protractor, and drill inspection apparatus. Furthermore, instruments developed for research are frequently re-designed for use in

production workshops to secure effective application of research results.

Low standards of drill performance are accepted as a matter of course in many companies, because the importance of correctly specifying and grinding drill point shape is not appreciated. Considerably increased drill life has been achieved as a result of investigations into the effect of point angle, relief angle, and other features of the drill shape. In the same way studies of reamer shape and operating conditions have led to improved finish and accuracy of reamed holes.

Tapping operations can involve various difficulties, ranging from geometrical inaccuracies in the threaded holes to tap breakage, which may necessitate a lengthy extraction operation or the scrapping of a component. Accordingly, tests have been made to determine the effect of percentage depth of thread on torque. Complementary tests were concerned with the effect of depth of thread on the mechanical strength of threaded assemblies.

Observations have shown that substantial savings can be made in industry by improving methods of grinding single point tools. In a factory employing 1,500, considerable economies were effected by the introduction of controlled tool grinding techniques and improved administration. Other aspects studied include the cost of grinding by different techniques, and the effects of tool surface finish on tool life and workpiece surface finish. An investigation has recently been completed into the performance of a range of makes of ceramic tools when turning alloy steel, as compared with that of cemented carbide tools used under similar circumstances. Special attention was given to vibration, which has a particularly destructive effect on the performance of ceramic tools.

Several comprehensive investigations into various aspects of the selection and use of different types of cutting fluid have been completed. Because the cooling, as distinct from the lubricating, property of a cutting fluid may be of considerable importance at moderate and high cutting speeds, it has been suggested that mains water may be satisfactory, provided it can be treated to make it non-corrosive. Performance tests have been made on two oil-less water-based cutting fluids, as compared with conventional soluble oil emulsions. In addition, the corrosive effects of the fluids on the type of cast iron used in machine tools has been investigated.

A recent development in PERA's metal cutting research is the establishment of a laboratory in which radioactive cutting tools will be used. It is expected that the technique, when developed, will provide information about the metal cutting process which cannot be obtained by conventional wear studies.

Metal Forming Research

In recent years there has been a progressive intensification and expansion of the Association's metal forming researches, and industrial application of their results has yielded savings of up to £30,000 per annum in production costs. The replacement of machining by new forming processes is a particularly fruitful source of economy in production. The cold extrusion process, for example, is resulting in substantial savings in capital expenditure, handling, operation times, and material consumption, in the production of a wide range of components.

Although cold extrusion has been used for the manufacture of collapsible tubes in soft metals for about a hundred years, only comparatively recently have techniques been developed for the cold extrusion of relatively high strength materials such as steel, copper and aluminium alloys. The process has been vigorously exploited overseas, and its adoption in this country will no doubt be accelerated by the extensive practical work in progress in the PERA laboratories.

The principal advantage of cold extrusion is the facility with which a wide range of components can be produced from a cold slug of metal in a single stroke of a press with relatively simple tools. One cold extrusion operation may replace several deep drawing operations with inter-stage anneals, but the most promising field of application for the process is in the replacement of machined components, and this has scarcely been touched, as yet.

The technical criteria of greatest interest in cold extrusion are the extrusion forces, the dimensional accuracy and surface finish of the extrusion, the mechanical properties of the extrusion, and the life of punches and dies, and these are among the aspects studied by the Association. Future research will be increasingly concerned with the problems raised by applications of the process to a wide range of components in steel and other high strength materials. The specification, microstructure and physical properties are of critical importance, and the effects of these factors are now being investigated for steels containing up to 0·3% carbon. A further factor of fundamental importance is the lubrication of the slug, and investigations are in progress to determine the effect on extrusion forces of the thickness of phosphate coating and its crystal size.

Besides investigations on general aspects of the process, pilot development projects are being undertaken to determine the practicability of cold extruding particular components required by industry. Equipment for these projects includes a large single-action eccentric-type press designed especially for the cold extrusion of steel, which has a rated capacity of 1,000 tons at 6 in. from the bottom of its stroke. It operates at a speed of

Part of the main workshop.

8 strokes/min., and is driven by a 250 h.p. motor.

Research has been carried out with a view to developing a technique of finish blanking which will produce smooth edges in contrast to the relatively rough edges produced by conventional blanking techniques. With thin material, decreasing the clearance between punch and die to about 2% of the thickness of the material is usually reasonably satisfactory, but with material thicker than $\frac{1}{4}$ in. a subsequent shaving operation is necessary, a procedure which is not particularly economic. Recent investigations have shown that aluminium, copper, carbon, and even alloy steels can be satisfactorily finish blanked to give a sheared surface condition which is at least comparable to, and in many cases better than, a shaved surface.

Deep drawing research includes an investigation to determine the relative efficiency of a number of lubricants when drawing various materials. A recent extension of this work has indicated that when drawing under special conditions outside the range of normal industrial practice, the state of lubrication existing between the interface of tool and workpiece material can be largely hydrodynamic in nature, instead of the more usual boundary type of lubrication. The consequent reduction of friction can significantly increase the maximum depth of draw obtainable, and should also reduce the need for special and expensive lubricants.

The thread rolling characteristics of a number of materials have been investigated, and the relationships found between radial rolling forces and penetration, for each material, suggest that tensile strength gives a better indication of penetration resistance than hardness. Some modification of the results may be necessary when further investigations involving tangential rolling forces are completed. Other thread rolling research has been directed towards the establishment of the optimum blank diameters for various materials.

Machine Tool Research

The general objective of PERA's machine tool research is to determine the principles of design, construction, and operation which contribute to the highest efficiency in the manufacture and use of machine tools. Such research normally includes a study of the accuracy of machines, observations of power and efficiency machining tests, deflection tests, vibration tests, etc.

Substantial progress has been made in an investigation into various aspects of machine tool slideway lubrication, and a report is being prepared on the influence of different types of surface, lubricant viscosity, load per unit area, and sliding speed on various factors, including the transition from boundary to hydrodynamic lubrication, stick-slip, friction forces, etc.

Present limits of speed, feed, tool life, surface finish, and accuracy in everyday production practice are often set by the vibration characteristics of machines and cutting tools. A growing number of makers and users of machine tools are recognising the need for trained engineers who can interpret and apply the results of vibration work, and several member firms have seconded engineers to the Association for periods of training lasting at least twelve months. The results of PERA's general researches into vibration, and of the special investigations carried out for individual members, have emphasized the need for rapid expansion of research in this field, and have indicated the lines it should take.

Automation

In 1955, a technical committee was set up to consider aspects of research which would be likely to help industry in the further development and application of automatic machine control and other features of mechanization which could be described as coming within the general scope of automation. Since then the Association has been carrying out an operational research into a wide range of automation equipment to assist members in selecting and applying these devices. To obtain direct experience of the problems involved in automation and to expedite the Association's investigations, several member firms have seconded engineers to PERA for periods of several months.

A report was recently issued to members on hoppers and selector devices for machine tools and presses. Other reports will cover work loading and unloading equipment, such as magazines, mechanical hands, iron hands, etc.; work clamping equipment, work conveying equipment: the application of various types of automation equipment in machining and pressworking in small and large quantity production; and transfer machine tools and presses.

Other Services

Space permits no more than a brief mention of two other aspects of PERA's work, namely the information and education services. The former deals with requests for assistance which do not necessitate practical research, and arranges liaison visits to member companies to stimulate the most prompt and effective application of PERA's recommendations, and to advise on various production matters. A monthly bulletin is circulated to members, and a number of films have been made on various aspects of the Association's work.

To help firms to obtain the maximum economic return from its membership, the Association devotes a significant part of its resources to the education and training of key personnel at all levels of industry. More than a thousand foremen, superintendents, methods engineers, designers, etc., have attended intensive five-day courses on improved production techniques. In addition a six-month student course is held twice a year to provide promising young engineers in member firms with basic training in research techniques and equipment, and to inculcate an analytical approach to the solution of technical problems.

Australian Foil Mill

THE British Aluminium Co., Ltd., London, and Aluminium, Ltd., Montreal, have announced further details concerning their new foil mill venture, Aluminium Foils (Australia) Pty., Ltd., a wholly-owned subsidiary of Australian Aluminium Co., Ltd., which is in turn jointly owned by the British and Canadian companies. The new enterprise will be the only aluminium foil mill in Australia which produces a full range of products. It will be equipped with modern high-speed foil rolling and finishing machinery, with an initial capacity of 1,500 tons per annum. The products will include both plain foil and all types of embossed, paper-backed, coloured and printed foils, etc., for the tobacco, confectionery, radio, dairy and packaging industries, for sale mainly on the Australian market. The new plant will be situated at Sydney, New South Wales, and the estimated capital cost of the first stage of the project is A.£1,000,000.

High Strength Weldable Steels*

By K. J. Irvine, B.Sc., Ph.D.

United Steel Cos. Ltd., Research and Development Dept.

High strength steels are now being widely used in welded construction. Following a consideration of the requirements of a high strength structural steel, the author discusses the various ways in which steels can be strengthened and the factors influencing weldability, pointing out the advantages of a bainitic structure.

A VERY large proportion of the steel that is made is used for structural purposes and the bulk of this is mild steel. Particularly in recent years, welding has become established as the major fabrication process and, consequently, both the mechanical properties and welding characteristics of mild steel must be taken as a yardstick for comparing any improved steels.

It is natural that considerable attention has been given to the development of higher strength steels, but any increase in strength has always had to be considered in relation to the welding properties, the cost, and the difficulties associated with steelmaking. For this reason there has been no widespread replacement of mild steel by these stronger alloys, except for applications where the advantages are easily realised. Typical applications for higher strength steels are static structures such as framed steel buildings, bridges and tanks, vehicles, ships, and earth-moving equipment.

High Strength Structural Steels

There has been developed over a period of years a group of low alloy high strength structural steels, which has been defined by the A.I.S.I. as follows :—

> " High strength low alloy steels are a specific class of steels in which enhanced mechanical properties and, in most cases, good resistance to corrosion are obtained by the intentional incorporation of one or more alloying elements other than carbon. These steels are generally supplied to minimum mechanical properties, usually in the as-rolled condition, or as annealed, normalised or stress-relieved, according to the requirements for welding."

When the recent developments in high strength structural steels are considered, it will be realised that this definition is no longer adequate, since heat treatments such as quenching and tempering have been introduced.

The main features of these high strength structural steels are as follows :—

Mechanical Strength

Mild steel itself was an improvement on the previously used wrought iron and its use enabled the strength to be increased from 20 tons/sq. in. tensile strength, with a yield point of 10 tons/sq. in. to 30 tons/sq. in. tensile strength and 15 tons/sq. in. yield point. If the properties of mild steel are taken as the base for comparing high strength steels, it will be found that both the tensile strength and the yield point to tensile strength ratio have been increased. Steels have been produced with tensile strengths between 40 and 70 tons/sq. in. and with a high proof stress/tensile strength ratio, although it should be emphasised that so far the use of these higher strength steels has been limited. This is partly because engineering designers have not felt confident in utilising the maximum properties, and also because frequently other properties are of equal importance, for example, stiffness or rigidity. Another aspect, however, is that the field of application has widened, and because of the intricate welding involved, high strength weldable steels have been used for structures such as aircraft engine casings.

Fabrication

A very important property of a structural steel is its ability to be fabricated by conventional methods. This fabrication may include drastic mechanical forming such as shearing, punching, hot and cold bending, and brazing. The material should also be suitable for flame cutting. It will be appreciated, therefore, that if the steel is one having a high tensile strength, then it must be capable of softening by a simple heat treatment.

Corrosion and Abrasion Resistance

It is an essential feature of many high strength structural steels that they possess superior corrosion resistance to mild steel. In many cases it is not possible to protect them adequately by painting, because the paint is removed by abrasion. In designing a structure, it is necessary to work on the basis of the section which will be produced by the amount of corrosion which occurs during the normal service life. In some cases (such as mineral carrying wagons), the section of the steel may be reduced to one half during the normal service life. There are two aspects to this problem, of which the first is the rate of corrosion under atmospheric conditions. This can be improved by the addition to the steel of such elements as copper or chromium, and corrosion rates one half or one third that of mild steel can be obtained. The second aspect is the rate at which the corrosion products are abraded from the surface, and fortunately these same alloying elements produce a tough and adherent corrosion product.

Welding

This is a property which is essential for practically all the applications of high strength structural steels. The three important aspects of welding which must be considered are :—

(*a*) the steel,

(*b*) the electrode, and

(*c*) the technique.

It is possible, by paying special attention to the welding

* Based on a lecture recently given to the Manchester Metallurgical Society.

technique and using pre-heating and post-heating, to weld difficult steels satisfactorily. In recent years there have also been considerable developments in welding electrodes, particularly with regard to low hydrogen coatings, which have eased the problem of welding high tensile strength steel. However, the main aspect of welding which will be dealt with in this paper concerns the steel itself and the susceptibility to cracking in the heat-affected zone.

The welding operation produces a considerable amount of heating in the parent plate adjacent to the weld. The critical region is where temperatures above 900° C. are produced because, after welding, the heat is rapidly conducted away to the cooler part of the plate and may produce a quenching effect and associated stresses. Since grain growth may also be produced, which lowers the ductility and impact resistance, this region may be susceptible to cracking.

Another fact which must be considered with high tensile steels is that immediately adjacent to the quenched zone there will be a region heated to between 650° and 850° C., in which softening may occur. Consequently, a weldable steel must not only resist a quenching operation, but it must also withstand tempering.

The Scope for Strength

The strength of a steel depends largely on its microstructure, and when considering the possible strength which can be obtained in a high strength structural steel, the structures can be classified as follows :—

(*a*) ferrite/pearlite,

(*b*) bainitic, and

(*c*) martensitic.

Developments have taken place to produce high strength structural steels in each of these categories, and these developments will now be discussed.

Ferrite/Pearlite Structures

Mild steel itself is, of course, a ferrite/pearlite structure with a microstructure consisting of polygonal ferrite grains and a small amount of pearlite. It is either by altering the properties of these two constituents or by altering the relative proportions of them that the structure can be strengthened. These possibilities can be considered separately.

(1) The ferrite can be strengthened by the addition of alloying elements. These have a solid solution hardening effect and, providing reasonably large amounts are added, the tensile strength is raised (see Fig. 1).

(2) The addition of alloying elements has little effect on the properties of pearlite itself.

(3) Since pearlite is harder than ferrite, an increase in strength can be obtained by increasing the amount of pearlite in the microstructure. It is possible to do this either by increasing the carbon content or by the addition of alloying elements which lower the eutectoid composition.

(4) The properties are improved (particularly the yield point/tensile strength ratio), if the grain size is reduced. A finer grain size is obtained either by using a low finishing temperature in rolling or as a result of the effect of alloying elements in depressing the transformation temperature.

Since one alloying element may harden the ferrite, increase the proportion of pearlite and reduce the grain size, it is difficult to study these effects separately, but a considerable amount of information has now been collected on the resultant effect of alloy additions on the properties of low carbon steels. Resulting from this information improved steels have been produced, and an attempt will be made to describe the background to these developments. Much essential information, particularly with regard to transformation diagrams, is still not available, however, and research is at present being carried out to complete this.

It will be realised that some development took place before good welding characteristics were required. Consequently, more use could be made of carbon as a strengthening element, and many early structural steels contained up to 0·3% C. A 0·27% C, 1·12% Si, 0·72% Mn steel was used in 1907 for building the first *Mauretania*, and a 0·3/0·38% C, 1·2% Mn, 0·15% Si steel was used in 1932 to build the Sydney Bridge. For ship plate, the Admiralty had introduced the Admiralty D quality in 1920, which was approximately 0·3% C, 1·2% Mn. The experience behind the use of this D quality steel led in 1934 to the introduction of B.S. 548 as a high strength structural steel. The details of this steel were :—

B.S.S. 548.

Specified Analysis : C, 0·30% max. ; S and P, 0·05% max. each.

Typical Analysis : C, 0·27% ; Mn, 1·4–1·6% ; Si, 0·25% max.

Tensile Strength : 37–43 tons/sq. in.

Yield Point—
Plates $\frac{3}{4}$–$1\frac{1}{2}$ in. thick : 23 tons/sq. in.
Plates > $2\frac{3}{4}$ in. thick* : 19 tons/sq. in.

* The yield point falls about 1 ton/sq. in. for each $\frac{1}{2}$ in. increase in thickness.

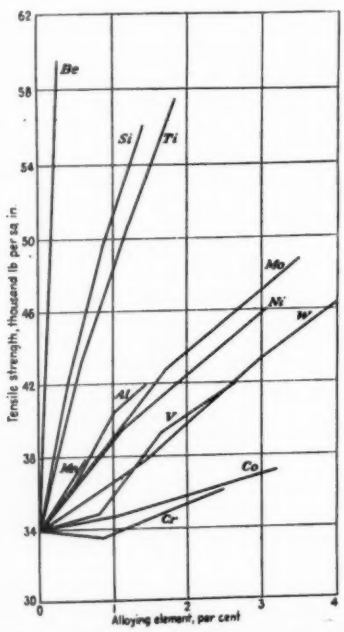


Fig. 1.—The effect of alloying elements on the hardness of iron (Lacy and Gensamer[24]).

This steel is also supplied containing ½% Cu, which improves corrosion resistance and raises the yield point by approximately 1 ton/sq. in.[1]

These properties represented an appreciable improvement compared with mild steel. However, it was at about this time that welding was becoming used on a large scale, and considerable difficulties were experienced in welding this type of steel. In order to obtain satisfactory welding it became necessary to modify the analysis. The carbon was reduced to 0·23% max. and the total of manganese, chromium, and nickel was limited to 1·8%. This became B.S. 968 in 1941, and typical composition and properties are given below.

B.S.S. 968.

Specified Analysis : C, 0·23% max.; Mn, 1·3–1·7%; Si, 0·10–0·30%; S and P, 0·05% max. each.

Tensile Strength :
Plates < ½ in. thick : 37–43 tons/sq. in.
Plates ½–1 in. thick : 35–41 tons/sq. in.
Plates > 1 in. thick : 33–39 tons/sq. in.

Yield Point :
Plates < ½ in. thick : 23 tons/sq. in.
Plates ½–1 in. thick : 21 tons/sq. in.
Plates > 1 in. thick : 19 tons/sq. in.

This steel is also available with a ½% Cu addition[1].

Of the steels using a single alloying element, only the C-Mn steel is used, because it provides an appreciable increase in strength at a reasonable cost. It seems clear that the B.S. 968 composition is the optimum for a simple C-Mn steel, and that 21 tons/sq. in. represents the maximum yield point which can be obtained in a steel of this type in 1 in. plate, whilst still retaining good welding characteristics. Steels of similar composition have also been used in Germany and the U.S.A.

For many applications, particularly for large pressure vessels, even this improved strength presents a serious limitation. In order to obtain sufficient strength, very thick plates have to be used. This, in itself, creates welding difficulties, but in addition, since thick plates have to be produced from large ingots, segregation becomes a problem. Harris[2] has quoted an example of the segregation found in 5 in. thick steel plate having a 0·24% C cast analysis, where a segregated band in the plate contained 0·33–0·35% C. This high carbon content was sufficient to cause hard-zone cracking in what should have been a weldable steel. The object of a high strength steel, therefore, is either to allow higher total stresses to be accommodated or to enable thinner plates to be used.

Because manganese provides increased strength at a very reasonable cost, most of the development of high strength steels has taken place from the C-Mn base composition. Barr has discussed the relative costs of different alloying elements in this type of steel[3] and has quoted the following costs :—

Element	*Increase in Ingot Cost per ton per 0·1% Addition* £ s. d.
Manganese	0 2 6
Silicon	0 2 9
Chromium	0 5 0
Nickel	0 10 0
Molybdenum	1 0 0
Vanadium	2 10 0

The attraction of manganese is obvious, and silicon would probably be more widely used were it not for difficulties in steelmaking.

The effect of various alloying elements has been investigated by Sims and Banta[4]. They found that carbon (above 0·2%) and manganese (above 1·5%) had a marked influence on hard zone cracking. Additions of silicon and chromium up to 1% to the Cr-Mn base steel produced little increase in strength. In contrast, an addition of 0·3% V or 0·4% Mo, whilst producing no increase in hard zone cracking, increased the strength by approximately 12 tons/sq. in. By limiting the carbon and manganese contents to 0·13–0·15% and 1·3%, respectively, and adding 0·5% Mo and 0·12% V, a yield point of 32 tons/sq. in. could be obtained from 1 in. plate in the as-rolled condition, with an extremely low tendency toward hard zone cracking.

An extensive programme of development work has been carried out by the British Welding Research Association. In order to limit the number of steels to be tested, the beneficial effect of a molybdenum addition to a C-Mn base was accepted, and then the effect of additions of Mn, Ni and Cr was examined.[5] The results were assessed on the basis of the effect of the resulting alloy composition on strength and weld cracking. It was shown that from the series of Mn-Ni-Cr-Mo steels containing 0·25% Mo and 0·15% C, the steel containing approximately 0·8% Mn, 0·8% Ni and 0·8% Cr gave the best combination of mechanical strength and weldability, whilst another suitable steel was 0·14% C, 1·23% Mn, 0·5% Cr and 0·25% Mo, which also showed good properties and was nickel-free. These steels were selected for manufacture as 2-ton commercial casts. The tests carried out on the commercial casts[6] confirmed that the welding characteristics of both steels were good. In the tempered condition, yield points of 25 and 28 tons/sq. in. were obtained on the two steels. The indication was that either of these compositions would make a useful high strength weldable steel. Very similar properties were obtained when vanadium was substituted for molybdenum, although in each case the vanadium steels gave slightly lower tensile strengths for the same addition of alloying element. An interesting feature of these results was that the steels containing molybdenum showed evidence of a low temperature transformation product, which was absent in the steels containing vanadium. The presence of this constituent appeared to lower the 0·02% proof stress values (presumably due to the presence of internal stress) and this effect could only be removed when tempering was carried out. The difference between the molybdenum- and vanadium-containing steels was probably due to a slightly greater hardenability in the molybdenum steels, since the vanadium steels showed low temperature transformation products when cooled in thinner sections.[8]

The commercial development of steels of this type has been reported[10, 3]. The starting point for this development was the C-Mn steel B.S. 968, and Mackenzie and Pow[10] found that molybdenum and vanadium were the two most effective elements in raising the strength of a C-Mn steel. Whereas 35 tons/sq. in. tensile strength and 21 tons/sq. in. yield point were the best obtainable in a weldable C-Mn steel, a composition of 0·17% C, 1·5% Mn, 0·23% Mo could give 40 tons/sq. in. tensile strength. The elastic limit was lower, but this could be raised by tempering, i.e., 1 hour at 500° C. gave a yield point at 27 tons/sq. in. A tempering temperature above 500° C. reduced these properties. It seems likely that the presence of a low temperature transformation product is responsible for these properties, as B.W.R.A. showed previously.

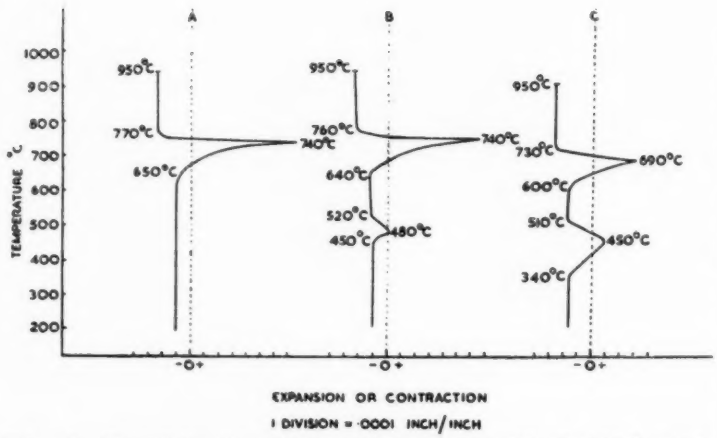


Fig. 2.—Transformation characteristics of three Mn-Cr-Mo-V steels cooled at rate for 5 in. thick plate. (Barr and Mackenzie.)

The compositions adopted for commercial production were :—

W. 24.

Analysis : C, 0·20% ; Si, 0·3% max. ; Mn, 1·5% max. ; Ni, 0·5% max. ; Cr, 0·25% max. ; Mo, 0·15%.

Tensile Strength (1 in. plate) : 35–41 tons/sq. in.

Yield Point : 24 tons/sq. in.

W. 27.

Analysis : C, 0·18% ; Si, 0·3% max. ; Mn, 1·5% max. ; Ni, 0·5% max. ; Cr, 0·25% max. ; Mo, 0·3%.

Tensile Strength (1 in. plate) : 35–41 tons/sq. in.

Yield Point : 27 tons/sq. in.

The nickel and chromium additions were included to allow the use of alloy scrap.

These properties are developed by tempering between 400 and 600° C. It is not possible to obtain such high yield points in large section sizes. In order to be able to obtain the properties in large sections a modified composition was developed of which a typical analysis is :—

*W.*30 : C, 0·16% ; Mn, 1·24% ; Cr, 0·74% ; Mo, 0·2% ; V, 0·05%.

The following properties are obtainable in different section sizes :—

Thickness	0·05% *Proof Stress*	*Tensile Strength*
¾–1 in.	30	38–44
1–3 in.	27	36–42
3–6 in.	24	34–40

This steel has been described by Barr and Mackenzie[3] as being " semi-air-hardening " and, consequently, is just outside the ferrite/pearlite classification. However, this does indicate the maximum properties which can be obtained.

Little of the background physical metallurgy of this type of steel has been given, but some indication of the transformation occurring can be seen from Fig. 2. The three steels are :—

	C%	*Mn*%	*Cr*%	*Mo*%	*V*%	*Pearlite* %	*Bainite* %
A	0·15	1·09	0·49	0·24	0·07	100	0
B	0·16	1·24	0·49	0·28	0·07	85	15
C	0·16	1·58	0·52	0·28	0·07	55	45

It will be seen that by the time the W.30 analysis is approached there is a definite split in the transformation, so that only 55% occurs as ferrite, with the remaining 45% as a relatively low temperature bainite.

It seems clear from the work which has been described that the simplest steels which can be developed to improve the properties of a ferrite/pearlite structure are C-Mn, C-Mn-Mo, C-Mn-V and perhaps, C-Mn-Mo-V. Some indication of the physical metallurgy of such steels can be seen from Fig. 3. This shows the effect of the increasing alloy content on the isothermal transformation diagram. The general effect is for the line representing the start of transformation to be depressed and also moved to larger transformation times. The mechanical strength depends to a large extent on the transformation temperature, because a lower transformation temperature increases the proportion of pearlite and reduces the grain size. The slower transformation times also enable a lower transformation temperature to be obtained, because a lower part of the transformation line is intersected. The combination of these two effects is beneficial up to the point where the steel becomes air hardening. A mixed transformation has the disadvantage that the separation of ferrite concentrates the carbon in the remaining austenite, so that the final transformation is to a relatively high carbon bainite or martensite. A comparison between the microstructures obtained from Steels 1 and 3 (in Fig. 3) can be seen in Figs. 4 and 5.

Some comments can be made on the effect of individual alloying elements, although an extensive programme of research work by the author to investigate these effects is not yet completed. There appear to be two important effects of alloying elements, namely, depression of the transformation temperature and solid solution hardening. Of the elements mentioned so far, manganese and nickel are very effective in depressing the transformation

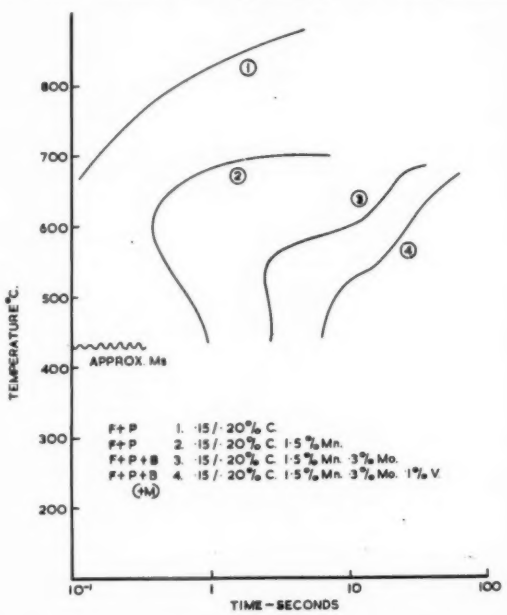
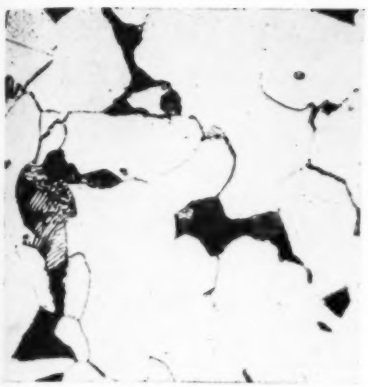
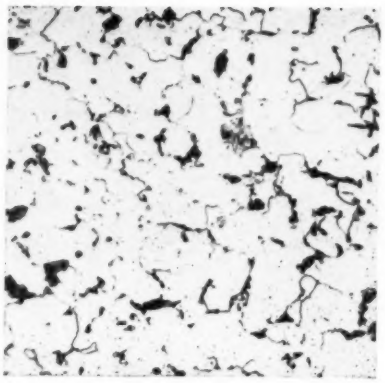


Fig. 3.—Isothermal diagrams for typical high strength weldable steels showing start of transformation.





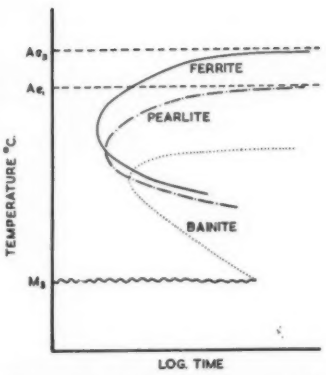


Fig. 4. (left)—Microstructure of mild steel. ×750. Fig. 5. (centre)—Microstructure of C-Mn-Mo high strength weldable steel. ×750. Fig. 6. (right)—Isothermal transformation diagram for plain carbon steel showing start of transformation.

temperature, and molybdenum and vanadium are effective in solid solution hardening. It also appears that both effects are necessary to obtain the optimum properties. This explains why single additions of alloying elements to a low manganese steel have little strengthening effect, and also why manganese alone is not very effective. It is the Mn-Mo or Mn-V compositions which give the best tensile strength. The solution-hardened, fine grain structure produced also has a high yield point/tensile strength ratio. When the steel becomes semi-air-hardening and a low temperature transformation product forms, the internal stresses associated with this transformation cause the proof stress to be reduced, and this effect can then only be overcome by tempering.

It would appear to be a reasonable conclusion that this category of high strength weldable steel has for its best mechanical properties a tensile strength of 40 tons/sq. in. and a yield point of 30 tons/sq. in. in thin sections.

The review given above refers mainly to British work, and examples of the steels which have been developed are given in Table I. In America, development took place on somewhat different lines, as controlled additions of phosphorus were frequently utilised. Phosphorus has a powerful effect in strengthening ferrite, although it also tends to introduce brittleness. Apart from the simple C-Mn steel, the types which have been developed in America are given in Table II. These steels contain additions of Cu, Ni, Mn, Cr and P. All the steels aim at producing tensile strengths between 30 and 40 tons/sq. in. with yield strengths up to 30 tons/sq. in.

One remaining development in this type of steel which should be mentioned is the utilisation of the precipitation hardening which can be obtained in copper-containing steels. An improved tensile strength can be obtained by a tempering treatment, but the improvement in properties is more noticeable at elevated temperatures.

When the compositions of these ferrite/pearlite high strength weldable steels are examined, it will be found that there are a very large number of different compositions containing various combinations of Mn, Ni, Cr, Mo, V, Cu and P. There is little justification for such a large number of steels, but they do provide different combinations of strength, corrosion resistance and weldability.

Bainitic Structures

Until recently, very little use was made of bainite as a metallurgical structure in low carbon steels, for the simple reason that this structure is difficult to produce

TABLE I.—BRITISH LOW ALLOY STEELS.

Name	C%	Mn%	Si%	P%	Cr%	Ni%	Mo%	V%	
				Approximate analysis					
Admiralty D	0·30	1·5		<0·05	—	—	—	—	
B.S.548*	<0·30	1·4/1·6	<0·25	<0·05	—	—	—	—	
B.S.968*	<0·23	1·3/1·7	0·1/0·35	<0·05	—	—	—	—	
B.W.R.A.—A	0·14	0·89	0·18	0·017	0·93	0·56	0·22	—	
B.W.R.A.—B	0·14	1·14	0·30	0·016	0·66	0·23	0·24	—	
Ducol W.24	0·2	<1·5	<0·3	0·05	0·25	0·5	0·15	—	
W.27	0·18	1·4	0·30	0·05	0·25	0·5	0·3	—	
W.30	<0·17	<1·50	<0·30	<0·05	<0·7	<0·30	<0·28	<0·10	$B = \frac{0·0013}{0·0035}$
Fortiweld	0·15	0·80	0·4	0·05	—	—	0·40/0·55	—	

* Also available with addition of 0·5% Cu.

TABLE II.—AMERICAN HIGH STRENGTH LOW ALLOY STEELS

Name	C%	Mn%	Si%	P%	Cr%	Ni%	Cu%	Mo%	V%	Zr%
Aldecor ..	0·12	0·15/0·40	0·35/0·75	0·08/0·15	—	—	0·35/0·65	0·16/0·28	—	—
Cor-Ten	0·12	0·20/0·50	0·25/0·75	0·07/0·15	0·50/1·25	0·65	0·25/0·55	—	—	—
Tri-Ten ..	0·22	1·25	0·10/0·30	0·045	—	0·50/1·0	0·3 /0·5	—	—	—
Hi-Steel ..	0·12	0·50/0·90	0·15	0·05/0·10	—	0·45/0·75	0·95/1·3	0·08/0·18	—	—
NAX	0·08/0·15	0·50/0·75	0·60/0·90	0·04	0·50/0·65	—	—	—	—	0·05/0·15
Jalloy 1 ..	0·13/0·18	1·0 /1·3	0·15/0·30	0·04	—	—	—	0·10/0·20	—	—
Jalten 1 ..	0·15	1·3	0·10	0·04	—	—	0·30	—	0·035/0·085	—

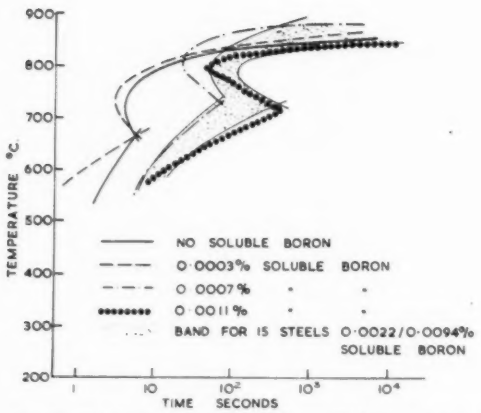


Fig. 7.—Isothermal transformation diagrams showing development of Fortiweld (low C-½% Mo-B) steel.

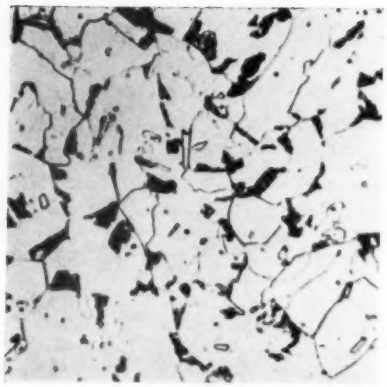


Fig. 8.—Microstructure of Fortiweld. ×750.

except in limited section sizes. If the equilibrium diagram which is shown in Fig. 6 is examined, it will be seen that the bainitic region is completely masked by the ferrite/pearlite transformation. This means that under normal cooling conditions it is impossible to get a completely bainitic structure. Under some cooling conditions, it may be possible to have a structure containing up to, say, 20% bainite, with the remainder ferrite/pearlite, or alternatively, under rapid cooling conditions, to have a structure consisting of mainly martensite with a small proportion of bainite. The only way in which a completely bainitic structure can be obtained is to use isothermal transformation, but because of the rapid transformation to ferrite, this would be extremely difficult to obtain in any reasonable section size.

The major-step forward in the production of bainitic steels came when the effect of boron in a low-carbon molybdenum steel was established[11, 12, 13]. The main effect of boron is that it retards the nucleation of ferrite at an austenite grain boundary, and in so doing, retards the formation of polygonal ferrite, so that this is only produced at slow cooling rates. Because the amount of alloying element is so small, however, the position of the bainitic transformation range is largely unaffected. The typical transformation diagram of this type of steel is shown in Fig. 7, and it will be seen that the polygonal ferrite transformation has been retarded to slow cooling rates, thus exposing the bainitic transformation region. Now, under quite a wide range of cooling rates, it is possible to obtain a completely bainitic structure. It was shown that this effect could only be obtained when both 0·5% Mo and B were present. The function of the molybdenum was to retard the ferrite and bainite transformations, and the boron then retarded mainly the polygonal ferrite transformation.

The steel which has been developed, Fortiweld, has the composition 0·1% C, 0·5% Mo, 0·003% B, a tensile strength of 40 tons/sq. in. and a 0·2% proof stress of 30 tons/sq. in. This again represents an appreciable increase compared with mild steel and, in fact, is equal to the maximum which can be obtained in a ferrite/

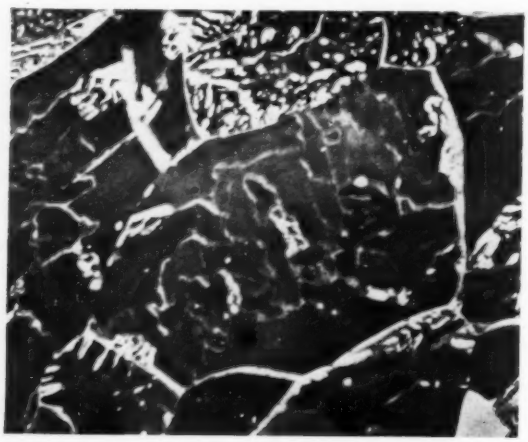


Fig. 9.—Electron micrograph of Fortiweld showing fine grain size. Formvar replica. ×3,000.

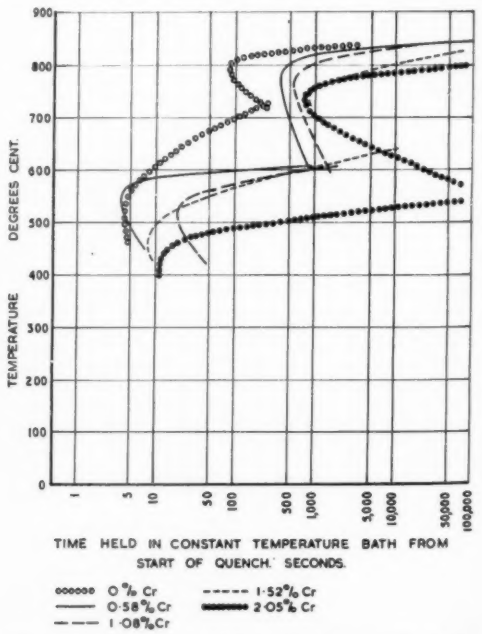


Fig. 10.—Isothermal transformation diagrams of higher strength bainitic steels showing start of transformation.

pearlite structure. Generally speaking, the yield point or 0·2% proof stress is the governing design criterion, and it will be seen therefore that the properties have been doubled, compared with mild steel. There is some interest in the reason for this increased tensile strength. If an optical micrograph is examined (Fig. 8), it is a little difficult to appreciate the reason for the increase in tensile strength, but when the steel is examined using an electron microscope (Fig. 9) it is found that the high strength is due to the fine ferrite grain size. This grain size is at least ten times smaller than that obtained with mild steel. This ferrite is no longer polygonal ferrite, but is bainitic ferrite, which forms by a shear mechanism in the temperature region 650°–550° C. instead of 850°–750° C.

When once the base composition is fixed at ½% Mo + B and the polygonal ferrite transformation is retarded, then the normal function of an alloying element in depressing the transformation temperatures can be utilised. If additions of elements such as manganese and chromium are made to the base composition, it will be found that the bainite transformation line is depressed. Typical diagrams are shown in Figs. 10 and 11, which indicate that the general transformation range is depressed from approximately 600° C. down as far as 300° C. It is also found, with each depression in transformation temperature, that the grain size becomes finer and the carbide particles become dispersed throughout the grains. These microstructural changes produce an increase in tensile strength, and the relationship shown in Fig. 12 between transformation temperature and tensile strength is obtained. Typical microstructures of steels in this range are given in Figs. 13–16.

When the cooling transformation characteristics are examined in detail, it is found that all the transformation occurs in the bainitic region. Typical dilatation curves are shown in Fig. 17, and it will be seen that there is a single transformation which occurs over a temperature range of approximately 80° C. for each steel composition. The transformation temperature range decreases as the steel is more highly alloyed, but even the highest tensile strength steel completes its transformation above 300° C. The contrast between these bainitic steels with a single transformation and a semi-air-hardening steel with a split transformation can be seen by comparing Figs. 2 and 17.

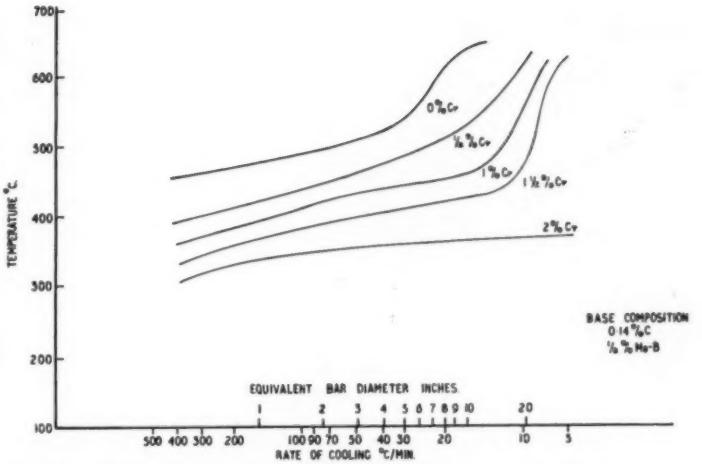


Fig. 11.—Continuous cooling diagrams for higher strength bainitic steels. Lines represent maximum rate of transformation.

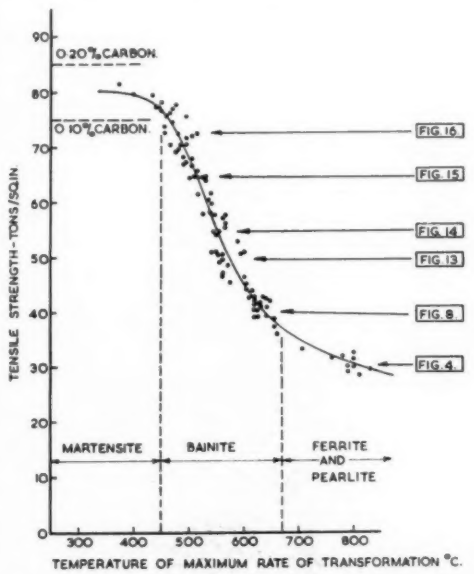


Fig. 12.—Relationship between transformation temperature and tensile strength. The position is indicated of steels whose microstructures are illustrated.

It should be emphasised that any alloying elements can be used in this way, and they each have a similar effect. There are two main effects due to the alloying elements; a depression of the transformation temperature and solid solution hardening in the small ferrite grains. It is found that an element such as manganese is very effective in depressing the transformation temperature, but it has a small solid solution hardening effect, whereas an element such as vanadium has a strong solid solution hardening effect without causing much depression of transformation temperature. The effect of each of these elements has been examined and their double effect established. It has been possible to express the effect of these alloying elements in an equation which relates tensile strength to the amount of alloying element added to the base composition.

Using this equation,

$$\text{T.S.} = 16 + 125\,\text{C} + 15\,(\text{Mn}+\text{Cr}) + 12\,\text{Mo} + 6\,\text{W} + 8\,\text{Ni} + 4\,\text{Cu} + 25\,(\text{V}+\text{Ti})$$

it is possible to calculate the tensile strength of the steel in the normalised condition to an accuracy of approximately 5 tons/sq. in. A detailed description of the physical metallurgy of this range of steels has recently been published.[14]

The commercial development of these higher strength Fortiweld steels is as yet only in the early stages. For reasons of cost, the two most suitable alloying elements are manganese and chromium. Two compositions which are being studied at the present time are given in Table III, together with typical properties. These properties show that there is a tendency for proof stress values to be low in the normalised condition, because the

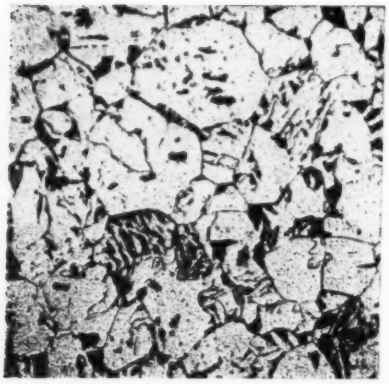


Fig. 13.—Bainitic steel of 48 tons/sq. in. tensile strength. ×750.

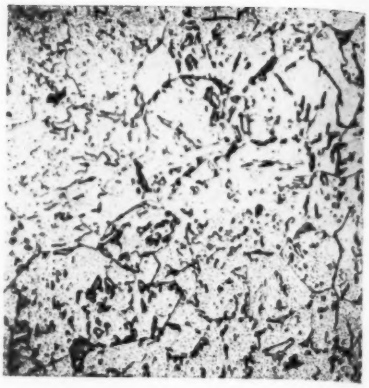


Fig. 14.—Bainitic steel of 54 tons/sq. in. tensile strength. ×750.

low transformation temperature produces some internal stress. A very light tempering operation is sufficient to remove this, however, and the 0·2% proof stress/tensile strength ratio is raised to approximately 0·8. A small vanadium addition (0·2–0·3%), can be made to the above compositions to improve the tempering resistance, to enable full mechanical properties to be obtained after stress relieving treatments.

Whilst it is claimed that the Mo-B base composition is the most effective way of obtaining a low carbon bainitic structure, other compositions will produce a similar structure, although usually over a more restricted range of section sizes. Work at present in progress indicates that molybdenum and nickel are the two most effective elements in producing a retarded ferrite formation which exposes the bainite transformation. The most complete account of steels of this type has been given by Nehl[15] who developed his steel from an earlier Cu-Ni steel and showed that improved mechanical properties, together with good welding characteristics, could be obtained when molybdenum was added. (The composition used was C 0·19%, Si 0·38%, Mn 1·12%, Cr 0·28%, Cu 0·98%, Ni 0·79%, Mo 0·27%.) This steel could give 45–70 tons/sq. in. tensile strength (depending upon section size). Nehl's conclusion was that the most desirable weldable steel would form a bainitic structure at the fast cooling rates adjacent to a weld, and also at the slow cooling rates obtaining in a thick plate after welding.

It is possible to produce similar properties with other combinations of alloying elements, provided suitable amounts of nickel (or manganese) and molybdenum are used, and another commercial development has been described by Bartocci.[16] Usually the useful section size is limited, but such compositions are very useful for developing boron-free welding electrodes, and a 3·5% Ni, 0·5% Mo composition has been developed as a high strength electrode.[17]

Martensitic Steels

It is well-known that the highest mechanical properties can be obtained from a low-carbon steel when it is in the quenched (or martensitic) and tempered condition. Naturally, therefore, attempts have been made to utilise quenched and tempered steels for high strength structural applications. The main difficulties were to develop satisfactory quenching methods for thin sections without producing serious distortion, and to obtain efficient quenching in large section sizes. This is rarely possible and it is probably reasonable to say that when the thickness is much above 1 in. the structure is essentially bainitic.

Sims and Banta[4] published results for a 0·18% C, 1·25% Mn steel in the quenched and tempered 540° C. condition. A yield point of 40 tons/sq. in. was obtained and, of course, the welding characteristics were the same as for as-rolled plate. In fact, the good mechanical properties indicated that the welding properties could be still further improved by lowering the carbon and manganese, whilst retaining adequate strength. A new composition (C, 0·15%; Mn, 0·79%; Si, 0·73%; Mo, 0·16%; Cr, 0·61%; Zr, 0·14%) was tested when quenched and tempered 650° C. This steel showed complete freedom from hard zone cracking and had a minimum yield point of 36 tons/sq. in. Mechanical property tests on this latter steel and on a 0·14% C,

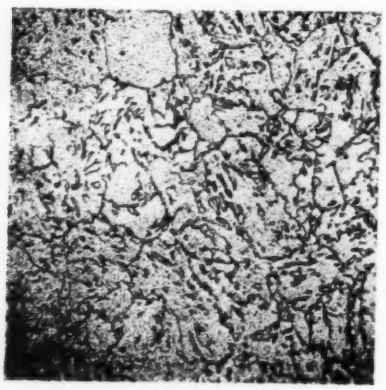


Fig. 15.—Bainitic steel of 64 tons/sq. in. tensile strength. ×750.

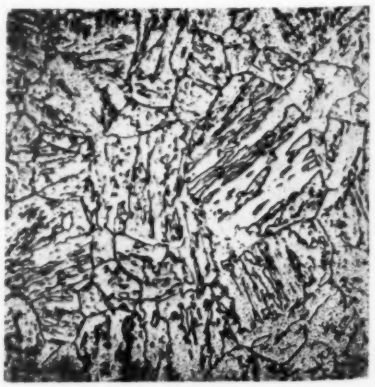


Fig. 16.—Bainitic steel of 72 tons/sq. in. tensile strength ×750.

1·24% Mn, 0·43% Mo steel, through the welds, indicated that the strength of the weld and heat-affected zones was equivalent to that of the plate.

The commercial use of quenched and tempered plates has been referred to by Harris[2]. A 0·16% C, 1·5% Mn, 0·5% Cr, 0·3% Mo, 0·07% V steel was used which, when quenched and tempered at 650° C., gave a tensile strength of 57 tons/sq. in. and a 0·2% proof stress of 53 tons/sq. in. At a lower carbon content of 0·12%, these figures were 46 and 41 tons/sq. in., respectively. No hard-zone cracking was experienced and similar properties to those quoted above were obtained when tested through the weld.

The most extensive work on quenched and tempered steels has been carried out in America and relates to a steel T.1.[18, 19, 20] The general theme of this work has been that a low carbon quenched and tempered steel offers the best combination of strength, weldability and impact properties. The specified composition is C, 0·1–0·2%; Mn, 0·6–1·0%; Si, 0·15–0·35%; Ni, 0·7–1·0%; Cr, 0·4–0·8%; Mo, 0·4–0·6%; V, 0·03–0·1%; Cu, 0·15–0·5%; B, 0·002–0·006%. This composition is largely intended to give adequate hardenability and the actual composition used varies for different section sizes. The minimum properties guaranteed in the quenched and tempered condition for ½–2 in. thickness are: tensile strength 47 tons/sq. in., yield point 40 tons/sq. in. It is claimed that the steel is readily weldable without pre-heat or post-heat, with full joint efficiency in the welds.

Factors Affecting the Weldability of High Strength Steels

The early work on weldability of steel usually fixed a maximum carbon content to avoid cracking, and calculated the chemical composition in terms of a carbon equivalent.[21] A typical formula was :—

$$\text{Carbon Equivalent} = C + \frac{Mn}{6} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{Cu}{13} + \frac{V}{5} + \frac{P}{2} + \frac{Ni}{15}$$

Later work has shown that one of the most important factors is the transformation temperature, since hard zone cracking results from the stresses which are produced during transformation. With many steel compositions a lower transformation temperature means that there is a greater tendency to form martensite, and it is this transformation which produces the largest stresses. A considerable amount of work has been carried out by the B.W.R.A. on hard zone cracking. It was shown[22, 23] that when welding Mn-Ni-Cr-Mo steels there was a critical temperature for the end of transformation to avoid hard zone cracking. When using rutile-coated electrodes, this temperature was 290° C.,

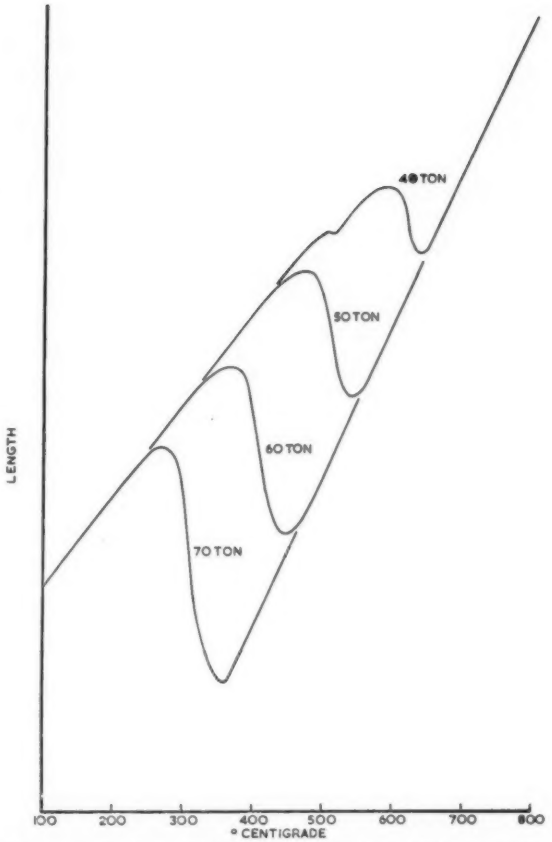


Fig. 17.—Typical dilatation curves for high strength bainitic steels showing transformation range.

but the use of a low hydrogen electrode reduced it to 240/250° C. (depending on the particular type of electrode). It was possible to calculate the relative efficiencies of alloying elements in terms of the depression of transformation temperature compared with the increase in tensile strength. The following values were obtained :—

C = 6° C./ton/sq. in.
Ni = 5° C./ton/sq. in.
Mn = 3° C./ton/sq. in.
Cr = 2° C./ton/sq. in.

This indicates that manganese and chromium are more suitable than carbon and nickel for high strength weldable steels. Using this test it can be shown that

TABLE III.—PROPERTIES OF FORTIWELD 55 AND FORTIWELD 70.

Steel	Analysis					Condition	Mechanical Properties (¼ in. diameter bar)							
							Tensile Strength (tons/sq. in.)	Proof Stress (ton/sq. in.)				Ratio of 0·2% Proof Stress to Tensile Strength	Reduction of Area (%)	Elongation (%)
	C%	Mo%	Mn%	Cr%	B%			0·2%	0·1%	0·05%	0·02%			
Fortiweld 55 ..	0·1	0·5	1	1	0·003	Normalised	57·8	41·8	35·8	29·8	22·8	0·73	54·7	31·5
						Normalised and tempered 400° C.	57·0	46·1	42·7	39·9	36·6	0·81	69·2	25·6
Fortiweld 70 ..	0·1	0·5	1·5	1·5	0·003	Normalised	75·6	50·5	42·3	34·9	26·8	0·66	59·0	19·2
						Normalised and tempered 400° C.	74·1	58·3	53·0	48·9	44·7	0·78	62·4	20·0

low C-Mn, Mn-Mo, or Mn-Mo-V steels combine good strength and weldability.

The same idea applies equally well to bainitic steels. It has been shown that the strength depends upon the bainitic transformation temperature, but the weldability depends upon the martensitic transformation temperature. Fortiweld has a bainitic transformation at 620° C. and a martensitic transformation at 450° C., and so is obviously perfectly weldable. The more highly alloyed Fortiweld steels must then be examined both for the bainite and martensite transformation ranges. The effect can be seen from Fig. 18, which shows how the increasing amounts of manganese and chromium depress both of these transformations. It will be seen that it is not until more than 3% of alloying element is added that the transformation is depressed to the dangerous temperature of 290° C. The critical temperature of 250° C. with a low hydrogen electrode would enable a higher alloy content to be used. This amount of alloying element is sufficient to produce a 70 tons/sq. in. steel.

The most suitable alloying element for increasing the strength of this type of steel is one which depresses the bainite transformation much more than the martensite transformation. Values are given below for the effect of 1% of alloying element on each of these transformations :—

	Temperature Depression (° C.) Produced by 1% of Alloying Element		*Ratio of Bs Depression to Ms Depression*
	Bs	*Ms*	
C ..	270	474	0·57
Mn ..	90	33	2·73
Ni ..	37	17	2·18
Cr ..	70	17	4·12
Mo	83	21	3·95

These results show that by far the worst element is carbon, and that the order of decreasing suitabilty is Cr, Mo, Mn, Ni and C. When the cost of the alloying elements is taken into account, it will be seen that the compositions selected for commercial development of higher strength Fortiweld steels, which contain Cr, Mo and Mn, represent the optimum for strength, cost and weldability.

The welding characteristics of quenched and tempered steels are exactly the same as for bainitic steels, since the initial condition of the plate has no effect on the structure produced in the heat-affected zone. An important point which needs to be considered is the tempering resistance of the steel to enable the full mechanical properties to be maintained in the region adjacent to the weld, where the steel is heated to 650°–850° C.

General Discussion

In spite of the large number of compositions which have been developed as high strength weldable steels, they can be classified fairly simply under the three main structural headings used previously. Over this range of steels it is possible to obtain tensile strengths up to 70 tons/sq. in. combined with reasonable weldability. It will be appreciated that the increased tensile strength is being obtained at an increased cost due to the larger amount of alloying element or to the added cost of heat treatment. It is suggested that the selection really falls into two categories.

(*a*) A steel having a ferrite/pearlite or high temperature bainitic structure, which can be used as-rolled or normalised and enables a tensile strength of 35–45 tons/sq. in. to be obtained with good welding characteristics and reasonable impact properties.

(*b*) A steel having a low temperature bainite or martensite structure, which is capable of giving either the maximum tensile strength (i.e., 55–70 tons/sq. in.) or the best impact properties (with a lower tensile strength—45–55 tons/sq. in.), or some combination of both. These steels also have good welding properties. For optimum properties both these types of steel will require tempering.

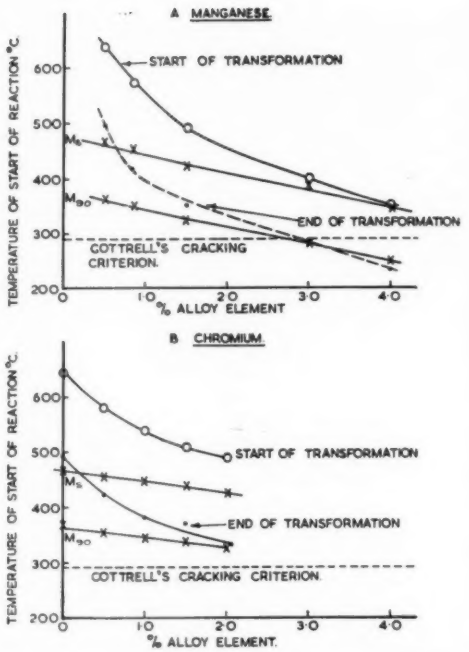


Fig. 18.—Transformation temperatures for bainitic steels in relation to the critical temperature for hard zone cracking.

Up to now there has been reasonably large scale application of steels in the first category, but only limited application of those in the second. In spite of the fact that they will be more expensive steels, it seems likely that it is the second category that will provide the outstanding developments within the next ten years.

There are strong reasons why bainitic steels should be considered for either category. At the lower strength end they offer much more consistent properties over a wide range of section sizes. It will be appreciated from the form of the transformation diagrams shown in Fig. 3, with a steep slope to the transformation curve, that the actual transformation temperature (and consequently the mechanical properties) will be very sensitive to section size. This particularly applies when an attempt is made to reach 30 tons/sq. in. minimum yield stress. In contrast, a bainitic steel has the polygonal ferrite retarded to very slow cooling rates and a relatively horizontal slope to the bainite transformation line. Consequently, the transformation temperature will remain constant for a wide range of section sizes and the mechanical properties will be very consistent.

At the higher strength end, the bainitic steels possess the advantages of the martensitic steels without the disadvantage of a quenching operation. When it is realised that in larger section sizes the structure is probably bainitic even with quenching, it seems desirable to aim at a low temperature bainitic structure for all section sizes.

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"Aluminium in Packaging" Symposium Luncheon

THE Council of the Aluminium Development Association entertained those taking part in the Symposium on Aluminium in Packaging, at a Luncheon at the Savoy Hotel on June 12th, when the Guest of Honour was MR. W. J. TAYLOR, C.B.E., M.P., Parliamentary Secretary to the Ministry of Supply.

The President of the Association, MR. S. E. CLOTWORTHY, (Managing Director, Northern Aluminium Co., Ltd.), in welcoming all the guests made brief references to the scope and activities of the Association, among which was the holding of one or more symposiums each year to survey achievements and prospects of aluminium in specific industries. Some 15% of all aluminium in the wrought forms fabricated in this country at present goes into packages: and the merits of aluminium for foil wrapping, for seals, for collapsible tubes and many other containers is fully established. Mr. Clotworthy quoted as an example the annual consumption of aluminium foil—exceeding 5,000 tons—for milk bottle tops in the U.K. alone. The greater expansion of self-service stores and pre-packaging generally would increase the part played by aluminium—but this applied not only to foodstuffs and pharmaceutical goods, but also to many industrial materials.

The President expressed appreciation for the presence of many leading members of the packaging industries, and particularly welcomed visitors from abroad. Considerable amusement as well as interest was aroused by his somewhat rueful reference to a quantity of beer, in aluminium cans, especially ordered for the occasion, but held up due to prevailing circumstances in a ship lying in the Thames very near the Savoy Hotel. The announcement that every effort would be made to ensure eventual delivery to each guest was received with acclamation.

MR. W. J. TAYLOR, C.B.E., M.P., Parliamentary Secretary to the Ministry of Supply, in response drew attention to the wide range of products to which aluminium was applied as a packaging material—a range extending from foil for cigarette packets to uses in connection with guided missiles. The aluminium industry, he continued, had a great responsibility in all their efforts to ensure the safe transit of goods from one place to another, so that they should reach their destination in the proper condition and moisture free. His Ministry was itself a larger user of aluminium, and its research establishments were always available for help and guidance which would be gladly given. Mr. Taylor concluded by affirming the interest of the Government and his Ministry in the work and progress of the Association.

At the technical sessions, more than 300 delegates from the packaging and aluminium industries discussed a total of eight papers on aluminium as a packaging material and on its various applications in that field. A small, but representative exhibition aroused considerable interest. The papers and the full discussion with authors' replies will be published in book form by the Association later in the year.

Iron and Steel Import Duties

UNDER the Import Duties (Exemptions) (No. 10), (No. 12) and (No. 16) Orders, 1957, the import duties on a wide range of iron and steel products are suspended until September 18th, 1958. After consultation with the Iron and Steel Board about the supply position, Her Majesty's Government have decided to prolong until December 31st, 1958, the suspension of import duty on (*a*) most types of cold-reduced sheets of a value of less than £90 per ton; and (*b*) hot-rolled strip over 18 in. wide in coils weighing more than 3 cwt. A new Order, The Import Duties (Exemptions) (No. 8) Order, 1958 (S.I. No. 797), has been made, and will come into operation on September 19th, 1958. Copies of the Order may be obtained from Her Majesty's Stationery Office or from any bookseller, price 3d. (by post 5d.).

The question of further suspension of duty on other iron and steel products after September 18th, 1958, is being examined; an announcement in respect of the duties on these other products will be made in due course.

Translations Available

SOME of the translations announced in Lists 24 and 25 of the Co-operative Translation Service are listed below. Translations identified by a number only may be obtained from the Service at The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

No. *Title*

743 ANTROPOVA *et al.*: "Influence of Deoxidation with Aluminium on the Quality of Structural Steel." *Stal*, 1957, Jan., 64–69. (£4).

749 WEYEL and WEIDE: "The New Light Section and Wire Rod Mill of the Klöckner-Hüttenwerk Haspe in Hagen-Haspe." *Stahl u. Eisen*, 1957, Oct. 17th, 1464–1476. (£6 10 0).

761 KHARASH *et al.*: "Problems in Sinter Production." (Including a Description of a 2,000 sq. ft. machine). *Stahl*, 1957, (2), 106–114. (Abridged). £6.

816 EGGERS: "The Mottling of Tinplate." *Arch. Eisenhüttenwesen*, 1957, Dec., 777–783. (£3 5 0).

856 KALAN: "Die Making by Means of Hot Pressing." *Kohaszati Lapok*, 1954, Sept., 390–399. (£3 10 0).

908 DAHL and LUEG: "Drawing and Push-pointing of Cold-rolled Steel Bars." *Stahl u. Eisen*, 1957, Dec. 12th, 1795–1802. (£5).

914 WEBER: "The Use of Fuel-oil in Forges." *Stahl u. Eisen*, 1958, Jan. 23rd, 87–92. (£4 5 0).

915 VOM ENDE and MAHN: "Operational Results when Blowing Basic Bessemer Melts Using the IRSID Opacimeter." *Stahl u. Eisen*, 1958, Apr. 3rd, 412–418. (£5 10 0).

952 PIOTRKOVSKII and ASHIKHMIN: "Automatic Regulation of Blast Furnace Working." *Stal*, 1957, (1), 16–20. (£3 10 0).

953 "Bibliography of Work by the Max-Planck Institute for Work Physiology in Dortmund"—June, 1956, June, 1957.—(£4).

954 ASTRAND: "Physiological Viewpoints on Working Positions and Work Kinetics." *Jernkont. Ann.*, 1955, (10), 817–828. (£3 10 0).

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Support Needed for Coil-Spring Research

BECAUSE of increased competition—rather than in spite of it—collaboration in the spring-making industry has become more important, especially so far as research is concerned. This is the opinion of Mr. R. Salter Bache, President of the Coil Spring Federation who, at the Federation's Annual Conference at Torquay last month, appealed for more members to support the industry's research organisation.

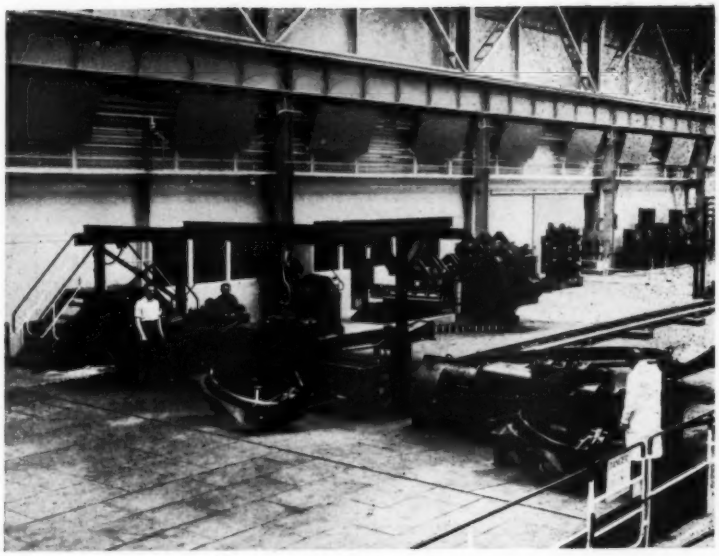
"The importance of the development of materials, processes and techniques in spring production is not only a matter of interest to spring manufacturers, but also to all users of springs, and as springs are of such importance to all branches of the engineering industry, it must be in their interests for all spring users to take an active part in research to improve spring performance." Mr. Salter Bache stressed the point that springs are frequently an essential but unnoticed component in a mechanism—yet their importance was often taken for granted.

Dealing with the activities of the Research Organisation, which last year was granted financial assistance by the Department of Scientific and Industrial Research for a further five years, he said that they were implementing the undertakings then given to D.S.I.R. by setting up new laboratories at Sheffield. The first full year of work under Mr. R. A. Haynes, the Director of Research, has been completed and a report on progress showed considerably increased activity.

The Technical Committee, under the Chairmanship of Mr. A. V. Jobling, who had recently succeeded Mr. Harry Singleton, was giving its full attention to improving facilities still further. The main points were providing facilities for research; planning to operate within the limit of the Federation's income; and endeavouring to increase that income. More space is now required to accommodate further research work, and the Federation is indebted to the British Iron and Steel Research Association for its co-operation in helping to provide the space. On increased membership, Mr. Bache said, "The matter of increasing our income is one of great importance and the Council have appointed a sub-committee to concentrate on the problem of acquiring new members. This committee has schemes in hand which we hope will prove effective. Although the committee is giving special attention to this matter, all members can be of considerable assistance in bringing the work of the Research Laboratories to the notice of their business contacts."

The Production of Wrought Titanium

I.C.I. Facilities Increased by Commissioning of South Wales Plant



Morgardshammer 5-stand guide mill for finishing rod.

I.C.I. interest in titanium began in 1949, when General Chemicals Division built a Kroll plant for the reduction of titanium tetrachloride by magnesium. At the same time, the Division was working on the development of a better and cheaper process, using sodium instead of magnesium. Experiments were started at Widnes Laboratory on a 7 lb. scale at the beginning of 1951, and it soon became apparent that technical objections to sodium had been exaggerated, and that the reaction could be satisfactorily carried out.

A semi-technical plant was erected in 1953 and a larger pilot plant started operating early in 1954. The results obtained confirmed the earlier indications regarding both the quality of the product and the efficiency of the process. Such was the faith of the Company in the sodium process that it took the decision to build a large-scale plant late in 1953, well before the pilot plant started operation. This large-scale plant, at Wilton in North Yorkshire, came into production in the first half of 1955 and has been in continuous operation since.

WITTON OPERATIONS

Melting

The melting of titanium presents the metallurgist with many difficult technical problems. In the first place, its melting point is very high—about 1,700° C., or 200° C. higher than that of steel. Secondly, molten titanium very readily combines with oxygen, nitrogen, carbon and many other chemicals. Since the presence in the titanium of even small quantities of such impurities hardens the metal and makes it less malleable, they must at all costs be avoided. So titanium cannot be melted in contact with air, and all melting must be carried out in a vacuum, or under a blanket of an inert gas, such as argon.

Another difficulty is that molten titanium will react with all known refractories, so that it cannot be melted in a refractory crucible or in a furnace lined with refractory, as is often the practice when melting other metals. The very difficult problem of containing the metal while it is being melted was solved by arc melting in a water-cooled copper crucible. Although copper melts at a temperature some 600° C. lower than titanium, a copper crucible can be used to hold molten titanium provided that the copper is kept very well cooled with water. The copper crucible used by I.C.I. Metals Division is surrounded by an outer jacket, and water is kept continuously circulating through the space between jacket and crucible. A gas-tight lid is fitted to the crucible, and the electrode passes into the crucible through a gas-tight gland.

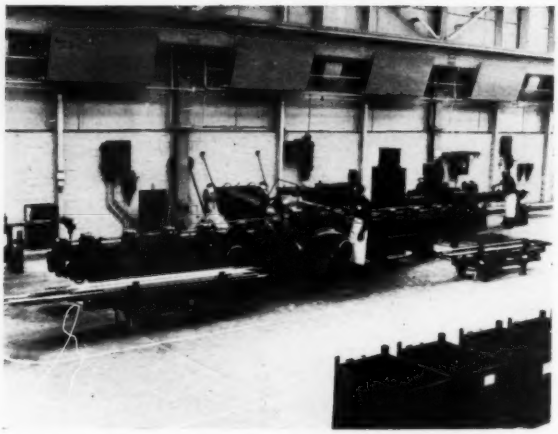
At its melting plant at Witton, Birmingham, Metals Division at first used a graphite electrode mounted in a water-cooled holder, and devised special methods whereby contamination of the melt by carbon from the electrode was reduced to a minimum. In this method of melting, an electric arc is initially struck between the electrode and a small quantity of titanium pellets at the bottom of the crucible. When these are fully melted a continuous feed of pellets is established.

The Division has since perfected a technique of melting which employs a titanium electrode, and it is this method which is used today. In the consumable electrode method, the electrode is made by compacting titanium powder (combined if necessary with other powdered metals to form an alloy) into a block with the required electrical characteristics. Unlike the graphite electrode, this compacted titanium electrode is not cooled. When the arc is struck, the electrode melts and the ingot is built up by the progressive melting of the electrode, there being no feed of pellets as with the graphite electrode melting process.

With both these methods the crucible must be evacuated or filled with argon, since contact with even small quantities of air or other gases spoils the melt. When the Metals Division Research Department started melting titanium, its first furnace produced an ingot weighing 5 lb. Today, ingots weighing 4,200 lb. are made.

New Furnaces

In March this year, Metals Division brought into operation the largest titanium melting furnace in



Lidkoping centreless grinding machine for bars up to 4 in. diameter.

Europe. This was one of three vacuum-melting furnaces supplied by W. C. Heraeus G.m.b.H. (Western Germany). Each is capable of producing ingots weighing up to 4,200 lb. The furnaces were delivered in January and the first 1-ton ingot was produced a little more than two months later. Within a few days, an ingot weighing 4,200 lb.—the largest ever produced outside the U.S.—was successfully melted. Although the new furnaces operate on the same basic principles as the smaller ones they are replacing, they embody many new features and represent a considerable advance.

The most obvious advantage they offer is in the increased size of the ingot—twice the size of any yet produced in Britain. This means that a much smaller proportion of the ingot is lost when surface imperfections are removed. More important still, the larger ingots can be rolled into long-length coiled strip, which is a more economic proposition than converting smaller ingots into sheets.

The new equipment also incorporates the most advanced measures yet devised to ensure safe working. All operations are carried out by remote control, and the furnaces themselves are installed in massive reinforced concrete cubicles affording complete protection. In the control room optical systems give the operator a clear view of the furnace interior throughout the melting process.

In the last three years, technical knowledge on titanium has accumulated so rapidly that the Company has twice replaced its entire complement of melting furnaces. In 1955, eighteen furnaces were needed for an output of 1,500 tons a year ; today, three are sufficient to produce over 2,000 tons a year.

Forging and Breaking-down

After cooling, the ingot is " dressed " to remove surface blemishes and heated for forging into slab or round billet. Heating to forging temperature must be done with extreme care, because at such temperatures the surface of the metal oxidises, forming a layer which has to be removed after forging. Both the temperature and the duration of the process are therefore strictly controlled.

When the forged product has been machined to remove the oxidised layer, it is again heated and then hot rolled in breaking-down mills to suitable size for processing into sheet or rod. Until recently, hot or cold rolling to finished gauge was carried out in the Witton factory on mills normally used for rolling copper and brass. As the cold rolling of titanium is appreciably more difficult than that of other non-ferrous metals, a considerable amount of work on copper and brass products was being displaced. To deal with this situation, the I.C.I. Board sanctioned the building of the new plant at Waunarlwydd, near Swansea, solely for the rolling of titanium and titanium alloys.

SOUTH WALES PLANT

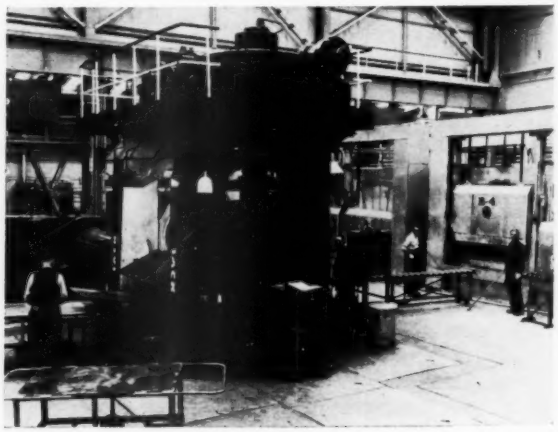
The factory at Waunarlwydd is laid out with two adjacent heavy bays, housing the rolling equipment for rod and for sheet, separated by a short distance from two light bays, one housing the rod finishing equipment and the other the sheet finishing equipment. A completely enclosed lean-to bay on the light building contains the pickling equipment.

Rod Plant

The main product of the rod plant is rolled round bar and rod, lathe turned, centreless turned, or centreless ground, in all I.C.I. alloys in diameters from about 5 in. down to 0·250 in., but the plant is also suitable for the production of simple rolled sections. The capacity of the rod plant is of the order of 1,500 tons per annum.

The starting stock consists of forged and machined bar from the melting plant—normally 5 in. square or 6 in. round—and the process is essentially one of preheating and hot rolling rod in closed passes to finished size. In general, a sequence of square passes, followed by alternate squares and ovals, is used, the final round section being derived from an oval of suitable size. After rolling, the rod is cut to length and for most applications centreless ground, centreless turned, or lathe turned, followed by etching in a hydrofluoric/nitric acid mixture and final inspection.

The essential requirements of the rolling equipment are speed and accuracy. Speed is necessary because titanium, owing to its low heat content, cools very quickly ; accuracy is essential to ensure the highest possible yield.



Reheating furnaces and Sack 4-high mill for hot rolling alloy sheet.

Rolling Equipment

The rolling equipment includes a Robertson 2-stand 3-high mill used for breaking-down bar stock and for finishing large diameter rounds by hand rolling. The mill is fed by two Birlec walking-beam electric furnaces, each capable of preheating billets up to 6 in. diameter by 6 ft. long.

Stock from the Robertson mill is fed to a Morgardshammer 5-stand guide mill for finishing rounds from about 2 in. to 0·25 in. diameter. This mill is of unique design in that the stands, which are detachable for roll changing and setting up, consist essentially of short rolls in roller-bearing chocks held together by very rigid screws. In this equipment, deflection of the rolls during rolling is extremely small, and rod of very accurate dimensions can be produced. This mill was selected mainly because of the yield improvements made possible by increased dimensional accuracy. It is fitted throughout with roller guides and is normally operated with repeaters. The exit speed from the fifth stand may be up to 1,500 ft./min. A small Birlec electric furnace is sited on the entry side of the mill for reheating small diameter rod stock.

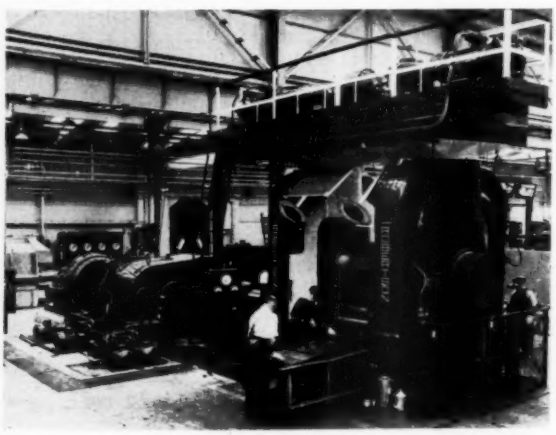
On the outgoing side of the Morgardshammer mill, and fed from the mill by roller conveyors, are cut-off shears and two Bronx reeling machines, which cover between them a range from ½ in. to 3 in. diameter. There is also a Loewy coiler for coiling the smaller diameter stock. Ancillary equipment in the bay includes abrasive cut-off machines and two gag presses used for the straightening of heavy bar and sections.

Finishing Equipment

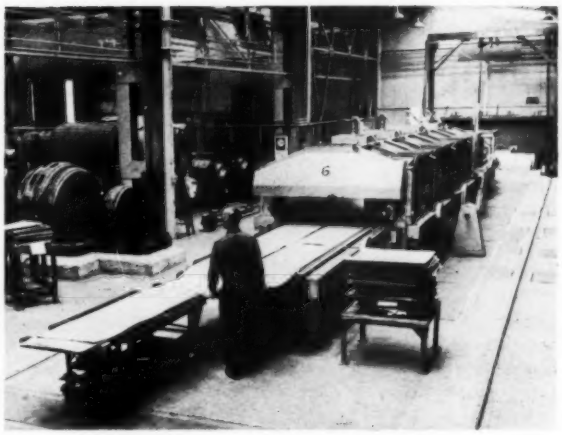
The finishing bay houses four centreless grinding machines—including a Lidkoping machine with powered tables capable of grinding bars up to 4 in. diameter—a centreless turning machine, a bar lathe, cut-off machines and inspection equipment. A G.W.B. electric furnace with facilities for rapid quenching is available for the heat treatment of alloy rod.

Sheet Plant

The products from the sheet side of the plant comprise a range of cold rolled sheet in Titanium 120, 130 and 160, in 2 ft. and 3 ft. widths, with the possibility of development of widths up to 4 ft. The thinnest material at present produced is 2 ft. × 0·008 in. in Titanium 120 and 130. Hot rolled alloy sheet (Titanium 317 and 318A) is supplied in widths up to 3 ft. and thicknesses down to about 0·024 in. The capacity of the plant depends on the type and gauge of product, but is of the order of 300 tons/annum of commercially pure titanium or, alternatively, 150 tons/annum of commercially pure metal and 50 tons of alloy sheet.



Robertson 4-high mill for cold rolling commercially pure sheet.



Continuous annealing furnace.

The base material for the plant consists of strip produced at Witton by hot rolling forged and machined slab. For commercially pure sheet, the process consists essentially of descaling and dressing the hot rolled blank, followed by a series of cold rolling and annealing operations, with some intermediate descaling and dressing operations, to final gauge, at which the sheet is annealed, descaled, pickled and sheared to size. Alloy sheet requires hot rolling to finished gauge, with intermediate descaling and dressing.

Rolling Equipment

The rolling equipment in the heavy bay consists of a series of three mills. The first is a Brightside 3-high mill with rolls of 68 in. barrel length. This unit is used for intermediate breaking-down of the hot rolled strip prior to finishing on 4-high mills.

A Robertson 4-high mill, also with 68 in. wide rolls, is used for cold rolling commercially pure sheet to gauges down to about 0·008 in. This mill is extremely powerful and as a result of modification is capable of rolling at pressures of up to 45 tons/in. width of material; this is one of the highest specific rolling loads employed in this country. It can be fitted with either 16½ in. or 14½ in. diameter work rolls.

A Sack 4-high mill with 60 in. rolls, used for alloy sheet hot rolling, is equipped with two Birlec electric preheating furnaces each with two heating chambers. The mill enables the very heavy loads necessary for hot rolling alloys to be applied.

Annealing Equipment

All process and final annealing of commercially pure and alloy sheet is carried out in a G.W.B. roller hearth continuous electric furnace capable of operating at up to 1,000° C. This method of annealing ensures that sheets remain flat during the process and also that the

layer of oxide scale is uniform and hence more easily removed.

Finishing Equipment

One end of the light bay is equipped for the receipt of material from Witton, and for cutting hot rolled strip to blank lengths. The bay also houses benches for sheet dressing, which is carried out by hand or machine scraping, roller levelling and stretching machines, guillotine shears and final inspection benches.

Descaling Plant

This plant is contained in an enclosed lean-to bay. Commercially pure sheet is descaled by acid pickling, which is preceded in some instances by pre-treatment in a special scale modification bath. Mechanical methods are normally used for descaling alloy sheet.

APPLICATIONS

U.K. output of wrought titanium, which was first marketed in this country in 1955, has until recently been absorbed largely by the aircraft industry, where the unique strength/weight ratio of the metal is of outstanding importance—it is about half the weight of steel and by alloying can be made as strong as high tensile steel. Recent changes in defence policy have, however, led to a reappraisal of the long-term requirements of the aircraft industry, and to the view that titanium's largest potential output probably lies in its use for the construction of chemical plant, where its remarkable resistance to corrosion promises to effect some quite revolutionary changes.

Titanium and titanium alloys can withstand attack by a wide variety of aggressive chemicals, including chlorine, chlorite and hypochlorite solutions, nitric acid, chromic acid, metallic chlorides, sulphides and organic acids, to name only a few. One of the outstanding attributes of titanium is its extremely high resistance to pitting and stress-corrosion cracking in chloride solutions and other liquids.

Tests assessing the resistance of titanium to the damaging effect of seawater—that most common of all corrosive media—show that, whereas cupro-nickel perforated in 500 hours in an impingement test using heavily polluted seawater, titanium was scarcely discoloured at the end of a period twenty times as long.

Titanium offers considerable advantages as a constructional material for chemical and allied plant. In existing plant, the use of components made from titanium in trouble-spots can reduce shut-down time and maintenance costs. Reduced manufacturing costs may well result from faster process working at higher temperatures than are possible with conventional materials. In new plant and processes, with plant specially designed to incorporate titanium, it is now possible for the first time to handle certain corrosive chemicals and to carry out chemical processes not hitherto possible on an industrial scale.

Anodically protected titanium carrying a small impressed current can now be considered for use in some of the most aggressive environments known to chemical engineers, including hot strong sulphuric acid, and phosphoric, hydrochloric, oxalic and formic acids. Another development of considerable promise is the use of platinised titanium anodes for the cathodic protection of steel structures and for electrolytic cells in chemical manufacture.

Although titanium is at present more costly than conventional structural metals, there are many instances where its unique properties may permit redesign of plant or equipment to reduce its size, and in this way such equipment in titanium would compare very favourably in price with equipment made from conventional materials. It is clear that maximum demand will only develop as prices are reduced from the present relatively high levels. At present, I.C.I. wrought titanium sheet sells at about £6 a pound and rod at £5 a pound. Last year, the Company reduced the average price of its wrought titanium products by about 10%.

Metals Division is carrying out considerable development work on the introduction of titanium into chemical plant, aided by Marston Excelsior, Ltd., of Wolverhampton, an I.C.I. subsidiary company, which has developed techniques for fabricating and welding the metal; other I.C.I. Divisions are installing titanium components in a number of plants.

All-titanium components already in use in the chemical and petroleum industries include gas/liquid nozzles, wet chlorine valves, orifice plates, springs, Hoerbiger-type compressor valve assemblies, pump impellers, filter plates, tower packing rings, agitators, thermometer pockets, resaturator grids and high-pressure needle valves. Titanium heat-exchangers are being used to recover heat from highly-corrosive chemical plant effluents, and anodising assemblies in titanium have proved to have a service life many times that of conventional materials.

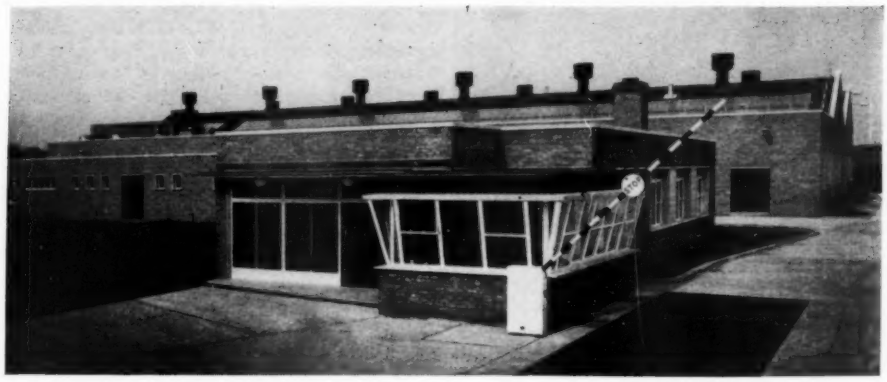
Because titanium is still a relatively expensive metal, an alternative has been found to fabricating large units (such as pressure or reaction vessels and the larger sizes of valves) entirely in titanium. This is to make the body of the vessel or component in cast iron or mild steel and then to line with thin titanium sheet any parts which come into contact with the corrosive medium. Spot welding techniques have been developed which are satisfactory even for components of intricate shape or for vessels incorporating branch pipes and end covers. Ancillary equipment such as cooling coils, agitators and thermowells, made entirely in titanium, can readily be incorporated.

A number of chemical and petro-chemical plant vessels and valves have been fabricated by these techniques, including a titanium-lined mild steel wedge-gate valve in service in a particularly aggressive mixture of trichlorethylene, hydrochloric acid and chlorine. A titanium-lined chlorine dioxide mixer has been giving excellent service for more than two years in an American paper mill, and a large rotary dryer, 40 ft. long × 5 ft. diameter, handling damp ammonium chloride crystals, is being lined on site with titanium sheet, replacing a stainless steel lining subject to severe pitting.

Metalectric Norwegian Order

Metalectric Furnaces, Ltd., Smethwick, have received an order from A/S National Industri, Oslo, for a continuous electric furnace for stress relieving silicon steel transformer laminations. The furnace will have an output of 850 lb./hr. and will be rated at 200 kW. Metalectric have pioneered the continuous method of stress relieving these laminations, and this is the second order for this kind of furnace which they have received from Norway within the past year. For this comparatively new process, the company have now received many orders for both home and abroad.

New Foundry for Precision Casting Steel



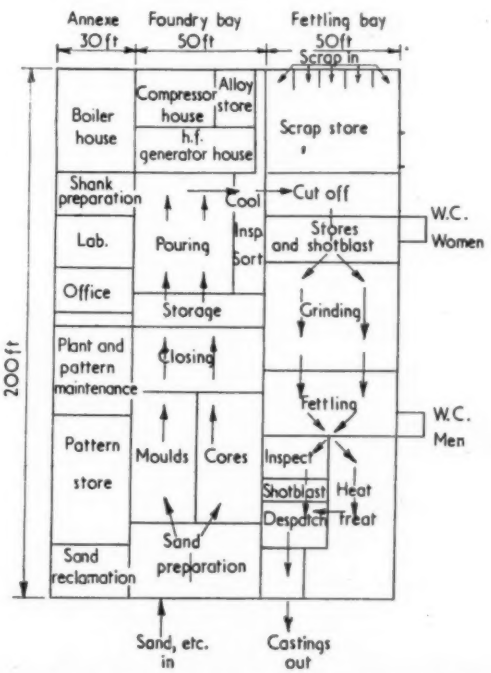
General view of the new factory.

THE increasingly competitive nature of world trade makes it imperative to study and adopt every possible means of reducing costs if this country is to hold its own. At a time like the present, when labour costs are increasing, the production of castings nearer to the final article, by eliminating or reducing machining and finishing operations, can make an effective contribution to cost reduction. Foreseeing a demand for steel castings of tolerances equal to, or better than, those achieved in iron casting, Samuel Osborn & Co., Ltd., have been actively engaged in development work on the production of precision castings, developments which have culminated in the building of a new foundry at Holbrook, near Sheffield, for the production of such castings, marketed under the name of Socast Steel Castings.

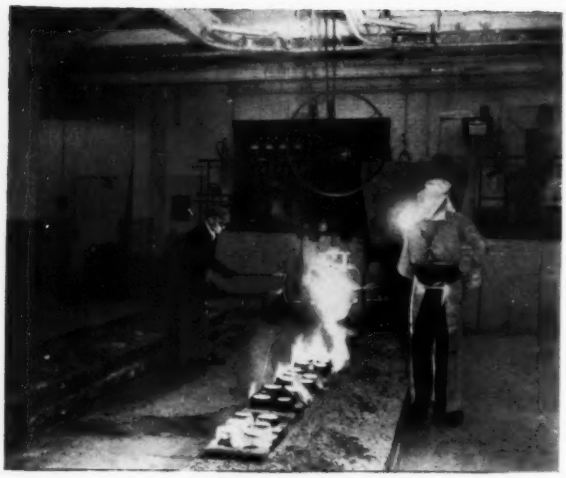
During visits to the U.S.A. and elsewhere in the Autumn of 1951, various members of the staff of Samuel Osborn & Co., Ltd., became aware of the possibilities of the shell mould process. Eighteen months later, moulds of this type were being made from a dump-box, and steel for casting was being melted in a small rocking arc furnace in a small pilot unit isolated from the main Osborn foundry. It was decided from the outset that the development of shell moulding and subsequently allied processes should be entirely separated from normal foundry production, as it was felt that a new process would not flourish if it had to take second place to a foundry producing 200 tons of steel castings per week by conventional techniques. By 1954 a 75 kVA. high frequency melting furnace, with one ½ cwt. body and two 1 cwt. bodies had been installed, and the same year it was decided that the pilot factory should become an independent unit within the Osborn Group (a profit and loss statement can provide a very useful means of measuring the success or otherwise of any productive unit). At the same time, within the field of development were included the Osborn-Shaw process, with which Osborn's have had a long association, and, at a much later date, a CO_2 block-mould process—a specialised development of the conventional CO_2 process which uses core-block moulding techniques.

The New Factory

By 1955, production in the pilot factory had been carried out sufficiently successfully and profitably to justify the preparation of plans for a new factory for the production of castings by the shell mould, Osborn-Shaw, and CO_2 processes. The plans allow for a progressive increase in trade over a period of five years, and plant has been installed according to a schedule, beginning with the installation of a high frequency melting furnace unit in July 1957. A second unit followed early in 1958, to allow for a build-up in production from just under 5 to 10 tons



Layout of the factory showing the main production areas.



Shanking from the monorail, with melting unit in background.

of finished castings per week on single-shift working.

As any one of the three processes is an essential part of the manufacture of small specialised steel castings, the factory has been laid out for production by all three processes, but it is intended that the present premises will ultimately be devoted to shell moulding only, in which case provision will have to be made for the other two processes. There is ample space available, as the company has acquired 75 acres of land to allow for such expansion and to permit the transfer to the new site at Holbrook of some of the existing Osborn activities : naturally, such a transfer is a very long term project.

As will be seen from the layout, the foundry comprises two 200 ft. bays, each 50 ft. wide, and a side annex, 30 ft. wide, of the same length. One of the large bays is devoted to melting and casting, together with the production of moulds and cores, whilst fettling, heat treatment and scrap storage are confined to the second bay. In the service annexe are works' offices, laboratories, pattern shop, pattern store and boiler room. An administrative block contains offices, canteen, rest-room and washing facilities for all employees. The aim throughout has been to provide an environment in which employees will be proud to work.

Shell Moulding Process

As implied by the name, a shell mould is a thin casing of fine silica sand bonded by phenolic resin. The dry mixture is applied to the pre-heated surface of a metal pattern, and the thermo-setting properties of the resin result in the surface of the pattern being covered by a "biscuit" which, after baking, is used to form one half of the mould. Together with the corresponding biscuit from the pattern for the other half mould, and any necessary cores, a complete mould is made, into which the metal is cast.

One of the features of shell moulding is the consistency of the moulds provided that satisfactory mixing of the sand and resin is achieved. A mechanical mixer with tumbling action is used at Holbrook, and a small proportion of an anti-separation agent is added to the accurately weighed sand and resin during the mixing process. This agent prevents separation of the binder from the sand and inhibits dusting during investment. It is intended later to install mixers capable of producing resin-coated sand, with which separation is impossible.

The moulding equipment includes an electrically heated twin-station machine operating two 24 in. × 22 in. pattern plates ; two smaller gas heated machines, each carrying two 16 × 14 in. plates ; and a twin-station machine using a pattern plate 24 × 16 in. and a gas heated oven. The shells are stored in mobile racks which serve to transport them to the closing and coring-up stations. The core-making equipment consists of two core makers, each capable of producing cores at a rate of 30/hr., and two manual core-fitting stations, each normally producing at a rate of 20/hr.

There are various techniques for closing shell moulds. At the Osborn foundry, one half of the shell is heated in an oven, and the core is placed into the other half shell, a thermo-setting resin being spread on the joint face of the cold half. The heated half is then placed in position on the cold half and the assembly put into a special closing machine, which incorporates rubber membranes which are sucked together when the air is evacuated from between them, pressing the two half shells into contact with each other.

The melting equipment comprises two Birlec high frequency units, both with 200 kVA. generators. The first unit has a 1 cwt. body and a 5 cwt. body, whilst the second unit has two 5 cwt bodies. Experience gained over the past few years has shown the importance of correct skimming of the metal in the furnace before tapping ; adequate skimming of the metal in the shank before pouring into moulds ; the use of a shank with a teapot spout ; and thorough cleaning and de-skulling of all ladles and shanks between successive heats. All these points have the single theme of cleanliness, which is most important if satisfactory castings are to be produced.

The monorail in the scrap area provides for the off-loading and storing of incoming alloys and the handling of charges from the scrap stores to the furnace platform. A monorail extension runs in front of the furnace from the shank and ladle preparation area, and also over the pouring troughs. Shanks and ladles are handled on the monorail by means of hoists. The shank is only lifted on and off the suspension equipment at the beginning or end of pouring. During pouring, the ladles or shanks are carried by the monorail, but are manually controlled for travel, rise, fall, and tilt. The monorail is designed to allow metal from any furnace to be poured on any one of the pouring troughs. Hand shanks are used for pouring metal into moulds for very small castings.

When laboratory release has been given to a batch of castings, it is shipped to the fettling shop, where the heads are removed by band saws, cut-off wheels, torches or powder-burning units. After cut-off, the castings are given an initial shot blast in a barrel-type machine, before proceeding along one of four lines provided with stations for grinding and fettling. A special feature of these lines are the fettling benches specially designed for the fettling of small precision steel castings, which are held in a vice and may be re-positioned several times during the fettling operations. Each bench is of the dual-station type, with a double ended bench grinder at one end, common to the two operators. Compressed air is available as a means of powering hand tools. Adequate ventilation is provided.

In a foundry producing castings in carbon steels, low alloy steels, austenitic manganese steel, stainless steels

and heat resisting steels, it is necessary to have adequate heat treatment facilities. Provision has been made in the first place for the treatment of 10 tons of finished castings per week, allowing for 24 hour operation of the furnace where necessary. Allowance has been made for additional furnaces should the rest of the factory go on double-shift working.

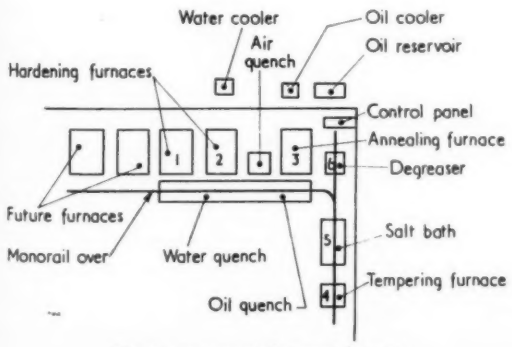
Furnaces 1 and 2 (see layout) are used for the treatment of stainless and austenitic manganese steels, which require air cooling or water quenching from high temperatures. A water quench tank is situated in front of these furnaces and there is adequate provision for atmosphere control. The furnaces have a temperature range of 650°—1,150° C.

Furnace 3 is used for annealing, normalising and oil quenching carbon and low alloy steels, and hardening martensitic stainless steels. The oil quenching tank is situated in front of this furnace, which has a temperature range of 650°—1,000° C., and provision for the atmosphere control so essential to minimise scaling, which could mar the accuracy achieved by using these precise moulding techniques.

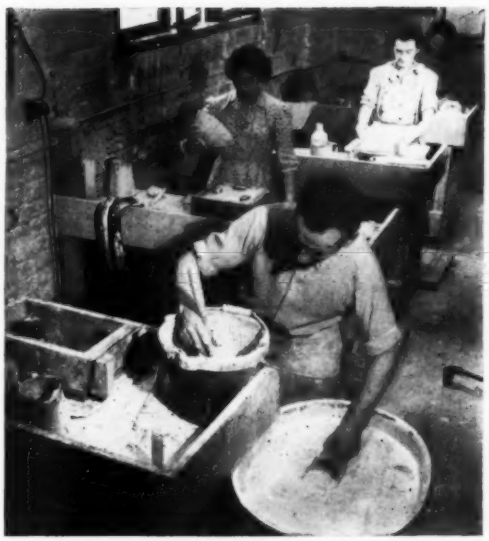
The remaining furnaces, 4 and 5, are, respectively, a natural-draught, gas-heated, air-recirculating tempering furnace with a temperature range of 100°—750° C., and a gas and air-blast heated twin-pot type salt bath. The pot size is 18 in. diameter × 24 in. deep, and this furnace is used when it is essential to avoid loss of dimensions due to scaling.

Water and oil quenching tanks are below floor level and are covered with hinged lids. All the furnaces are fitted with hinged chutes so that castings are directed into baskets in the quench tanks, the baskets being handled by chain blocks from the overhead monorail. Circulating cooling systems are provided for each tank. A degreasing tank is provided, and castings are given a final shot-blast in a cabinet type machine, before inspection, which may include magnetic crack detection, non-magnetic crack detection and radiography to supplement the chemical analysis and mechanical testing.

There are many applications where shell moulding is of value in obtaining a better casting than is possible in sand casting. Frequently, it makes possible the supply of steel castings in place of components which would otherwise have to be fabricated or machined from forgings or the solid. This is possible because of a number of factors. In the first place, the dry nature of the mould and the speed with which the metal enters it, permit thin metal sections to be specified, such as would only have been possible by final machining a few years ago.



Heat-treatment furnace layout.



Mould making by Osborn-Shaw process.

Secondly, the susceptibility of high-alloy steels to hot tearing is considerably reduced, thus reducing the restrictions on design. Finally, as mentioned earlier, the dimensional accuracy of the castings produced is such that expensive machining operations can be considerably reduced, and in some instances obviated. Castings varying in weight from a few ounces to 30-40 lb. are readily produced.

Osborn-Shaw Process

As the shell moulding process offers advantages unobtainable by conventional sand moulding, so the Osborn-Shaw process compensates for certain limitations in shell moulding. The process can be adapted for use with either wood or metal pattern equipment, and is therefore considerably more economical than the lost wax process.

The first stage of production is the manufacture of the master pattern, preferably in brass, bronze, steel or plaster. Wood can be used, but is not recommended where intricate shapes are required, or where large quantities are to be cast. A bench moulding technique has been adopted at Holbrook, and wooden moulding boxes are used, the mould material being poured over the pattern in the form of a slurry. The gelling reaction is so controlled that within a matter of a few seconds the slurry is changed to a tough rubbery gell, which eventually solidifies. The mould is stripped from the pattern whilst in the rubbery condition, making it possible to use patterns without any draw or taper, and in some instances with slight undercut. Immediately the moulds have been removed from the pattern they are placed on a firing table near to the moulding bench, to ensure the rapid removal of alcohol. Various refractory mixes are used ; in some cases use is made of a fine facing mix of sillimanite, with a backing mix of coarse molochite and used refractory. A unit mix of coarse and fine sillimanite or molochite is also used. After burning off the alcohol, the moulds are cooled before transferring to a closing station. The closed moulds can be stored for several days provided that care is taken to prevent foreign

Continued on page 36

Metallurgy in Nuclear Engineering

Survey of the Literature in 1957*

By J. Burkett, F.L.A.

Information Officer, Hawker Siddeley Nuclear Power Co., Ltd.

Although nuclear engineering is a comparatively new development, and in spite of the fact that much of the work carried out in this field cannot be published for security reasons, there is a growing volume of literature on the subject, as will be seen from the following pages, in which reference is made to those papers published last year which dealt with metallurgical aspects.

THIS survey of the work published in 1957 dealing with metallurgy in nuclear engineering is divided into three main parts. The first deals with materials of construction, their properties and the effects of irradiation on them; the second is concerned with the metallurgy of reactor fuels; and the final section is devoted to the welding of reactor materials.*

Materials of Construction

Metals in General

The physical and nuclear properties of a large number of reactor, fuel, coolant and structural materials have been compiled,[1] and McIntosh[2] demonstrates how the understanding of each specific chemical, physical and metallurgical characteristic in relation to reactor design aids critical selection from the many sources of metallurgical information. Weir *et al.*[3] outline the essential physical and mechanical properties which have to be considered in the design of high temperature systems, relating these factors to detailed design of structural members: they particularize the phenomena of strain cycling and relaxation. Stacy[4] surveys the strengths of metallic materials for high temperature service, and considers the usefulness of tungsten and molybdenum, particularly with reference to corrosion resistance, weldability, thermal expansion and deformation. He makes recommendations on those alloys most suitable for service above 1,500° F. (815° C.).

The metallurgical aspects of Calder Hall considered by Bishop[5] include uranium fabrication and canning; the selection of steels for pressure vessels; and the erection and stress relief of the latter. The creep test facilities installed at the materials research laboratory of the G.E.C. Atomic Energy Division at Erith have been described,[6] and further aspects of research being carried out by this company in the metallurgical field are covered in a paper by Dennis.[7]

The 13th Annual Conference of the National Association of Corrosion Engineers[8] concentrated on corrosion by high-purity water, and papers presented cover the measurement of corrosion products in high-temperature high-pressure water systems and the corrosion of aluminium. McIntosh[9] examines corrosion problems associated with water-cooled and moderated reactors, and reviews the corrosion behaviour of stainless steel and mild steel, zirconium and its alloys, aluminium and aluminium alloys, and the corrosion of magnesium alloy fuel cans. Experimental work on the corrosion of reactor systems by aqueous reactor fuel solutions is reported by McDuffie,[10] who discusses effects of UO_2SO_4 on titanium, platinum, austenitic stainless steels, zirconium, niobium alloys and zirconium alloys.

The stress-corrosion cracking problems of materials in the homogeneous reactor test (HRT) have been studied by Bohlmann and Adamson,[11] and Wacker and Griess[12] summarize the corrosion data collected during runs of the HRT mock-up operating on 0·042M UO_2SO_4, 0·024M H_2SO_4 and 0·0005M $CuSO_4$ at 280° C. and 1,400 lb./sq. in., with the oxygen content at near 500 p.p.m. Results are given of corrosion runs on titanium, Zircaloy-2 and stainless steel.

Ceramics and Cermets.

Several aspects of ceramics used in nuclear reactors were covered at an information meeting held at Oak Ridge,[13] which included discussions on the thermodynamic stability of refractory oxides; the melting points of UO_2, etc., radiation stability of certain ceramic materials; sinterable oxide powders; the oxidation of silicon carbide; and thoria-base metallo-ceramics, etc. Friedmann[14] has compiled a literature survey covering the development of cermets from 1950 to 1956.

Irradiation Effects in General.

Siegel[15] summarizes the types of nuclear radiation present in a reactor, and discusses changes in irradiated metals, semi-conductors, graphite, ionic crystals and fissionable materials.

Beryllium.

Miller[16] presents the physical and mechanical properties of beryllium and discusses the consolidation of the metal powder; the importance of particle size; corrosion resistance; health hazards; and future development. Williams[17] is also concerned with the hazards of the metal and its compounds, and Weber *et al.*[18] survey the properties of beryllium oxide and the carbides of beryllium, molybdenum, niobium, tantalum and titanium. Ditmars and Ginnings[19] conducted experiments to find the thermal conductivity of beryllium oxide over the

* This survey does not include U.K.A.E.A. reports, which are listed monthly in "Lists of Publications Available to the Public." The reports to be found in the references at the end of the survey are those of the U.S. Atomic Energy Commission. These reports are sent to the following depository libraries, from whom requests for loan should be made:—
The Central Public Libraries of Birmingham, Bristol, Kingston-upon-Hull, Leeds, Liverpool, London (Acton), Manchester, Newcastle-upon-Tyne, Nottingham and Sheffield.
In some instances reports are in the form of microcards, and special viewing apparatus is required. The above libraries either possess viewers or will advise about them.

temperature range 40–750° C. They applied a steady state longitudinal heat flow along a rod of high-fired BeO_2 surrounded by a tube with matching temperature gradient, to minimize radial heat loss. The corrosion resistance of beryllium to water has been investigated,[20] stagnant tests being made to determine the effects of production method, surface cold working; water quality and metal parity.

Boron.

Finlay[21] outlines the properties of the various forms of boron which make it an effective absorber for thermal neutrons with applications to control and shielding. Boron carbide is being used embedded in plastic sheets ; rolled into aluminium (boral) ; hot-pressed ; in the form of a bonded block ; or as a granular fill.

Graphite.

At a symposium organised by the Society of Chemical Industry, many features of industrial carbon and graphite were presented.[22] The session on graphite in the nuclear power industry included papers on the effects of neutron irradiation on physical properties ; the compatibility problems of graphite moderators ; physical properties affected by high temperature and irradiation ; fabrication problems ; developments in the gas purification of graphite. Fletcher and Snyder[23] present data on changes in the physical properties occurring in typical graphites after irradiation within the temperature range 30–150° C., and show that the physical properties are affected by variations in graphite type. Loch *et al.*[24] report on studies that they have made in the use of graphite for fuel elements.

Egelstaff[25] has measured the slow-neutron cross-section of graphite, comparing the results obtained from using a typical example of British graphite with those observed in a similar experiment in America. James,[26] in a study of neutron damage in graphite, estimates the energy stored in graphite crystals and in displaced carbon atoms, per neutron of a given initial energy. He indicates the relative damage produced by the neutron distributions existing at several points in a pile. Primak and Fuchs[27] have made a detailed study of fast neutron damage in nuclear reactors. Having developed a method for using the percentage decrease in electrical conductivity as a saturating property to formulate a linear dosage scale, they explain the ratio of the damage rates in irradiated graphite in terms of the different flux spectra existing in the irradiation facilities used. They identify the portion of the neutron flux spectrum responsible for radiation damage, and a method is described for comparing the radiation damage in different substances, or in different properties of a single substance.

Prosen and Valent,[28] of the National Bureau of Standards, have presented a series of reports on the measurement of the energy contents of irradiated graphite made by the heat-of-combustion method. Novick *et al.*[29] explored the extent of the Wigner effect and found that at any point in a pile it is sensitive to the local structural situation, being greater near a slug.

In experiments that were carried out by Bennett and Pearlman[30] on commercially available graphites of high density and low permeability, they made determinations of density, pore size and distribution, permeability toward air and liquid metals, and chemical analysis. In a study by Swarts[31] of the long-term interaction between molten uranium and graphite in the range 1,150–1,400° C., interim results indicate that an adherent, protective carbide coating forms on the graphite at a rate strongly dependent upon the temperature.

Aluminium and Magnesium.

In a survey of materials for organic cooled reactor pressure tubing, Burgess[32] considered magnesium alloys, aluminium alloys, Zircaloy-2, and mild steel. Aluminium is used in the Dounreay fuel elements and in the heavy water tank and a brief description has been given of the manufacturing and testing processes.[33] Riedinger[34] has collected the available information on the corrosion behaviour of aluminium alloys in high-temperature, pressurized water. The corrosion rate of alloys M400, M388 and X2219 increases with increasing velocity and *p*H. Phosphoric acid and the polyhydroxyanthraquinone compounds were used as inhibitors. Allen *et al.*[35] report on long-time tests to find the effect of various types of radiation on corrosion of 2S aluminium in simulated pile water. They conclude that, in general, radiation is not expected to accelerate corrosion. Blewitt *et al.*[36] examined the effects of structural and chemical defects in a low-temperature reactor on the low-temperature annealing peak of irradiated aluminium and copper.

Commercially available magnesium alloys have been studied by Lingafelter[37] as a material for process tubing for organic coolants. He tabulates dimensional tolerances, neutron cross-sections and high-temperature creep and tensile yield properties, concluding that these alloys do not seem to be suitable at 600° F. (315° C.) and 400 lb./sq. in. De Luca[38] has determined the interdiffusion rates between magnesium and zirconium over the range 500–640° C. The diffusion of magnesium into zirconium embrittled the latter, but did not change the appearance of its microstructure.

Molybdenum.

The effects of neutron irradiation on the mechanical properties of molybdenum and tungsten are discussed by Makin and Gillies.[39] Changes are apparent in mechanical properties of stress-relieved molybdenum and fully crystallized tungsten at 100° C., with a neutron flux of 5×10^9n/sq. cm.

Niobium.

McIntosh[40] traces the development of niobium as a reactor material because of its high melting point, excellent compatibility with uranium, good high-temperature strength ; and physical and mechanical properties. It is considered satisfactory with pure liquid metals at temperatures of 600° C., and above, but the corrosion rate perceptibly increases with small oxygen concentrations. The development of high temperature strength and corrosion resistant alloys is discussed. Tottle[41] reviews the physical and mechanical properties of niobium over the temperature range experienced in nuclear reactors. There is an increase in thermal conductivity, and a fairly slow decrease in tensile properties with a rise in temperature. Small additions of oxygen have a marked effect on tensile properties. Williams[42] gives an account of two possible methods for the production and fabrication of massive niobium metal —the first by melting, the other by compacting and sintering. O'Driscoll and Miller[43] report on a study made of the purification of the metal by sintering on both a laboratory and a commercial scale. The melting point of niobium has been re-determined by Schofield[44] using a non-refractory technique.

Cotter[45] briefly reviews world resources of niobium, its preparation and fabrication, chemistry and metallurgy, and its compatibility with uranium. Progress is reported in the production of what might now be termed the " medium-rare " metal.[46]

The effects of binary alloying additions on the oxidation and contamination resistance of niobium have been studied by Sims *et al.*[47] Tests were conducted in air at 600, 800 and 1,000° C., and it was found that zirconium, titanium, chromium and vanadium were effective in reducing oxygen diffusion. Other oxidation and contamination research is reported by Klopp *et al.*[48] who carried out measurements in the temperature range 600–1,200° C.

Williams and Pechin[49] investigated the Ta-Nb alloy system by means of X-ray, resistance and metallographic methods, and report that the system has solid solubility in all proportions.

Iron and Steel.

Smith *et al.*[50] discuss the creep, stress-relaxation and metallurgical properties of steels for steam power plant operating with steam temperatures above 950° F. (510° C.). Blumberg[51] makes a broad approach to the selection and behaviour considerations of materials for modern high-temperature, high-pressure steam power plant piping. He makes a summary of the steels currently used, and analyses the potentials of super-strength alloys. A review is given of the operating experience and difficulties with austenitic steels at 1,050 and 1,100° F. (565–595° C.) in the form of high-temperature steam piping. Curran and Rankin[52] refer particularly to specific turbines and power-generation stations.

The corrosion of Armco iron and high-purity iron has been measured over the range 240–360° C. in high-temperature water. Douglas and Zyzes[53] describe a method of measurement which uses small autoclaves where the gas space is filled with a known amount of helium. After corrosion, a gas sample is analysed, and the amount of hydrogen produced can be calculated from the pressure, volume, temperature and gas analysis. Boyd and Pray[54] describe the corrosion characteristics of stainless steels in degassed super-critical water at 800, 1,000 and 1,350° F. (425, 540 and 730° C.), and at a pressure of 500 lb./sq. in. All alloys suffered some decarburization and carbide precipitation. Armco 17-4PH, Armco 17-7PH and Hastelloy F alloys were the most resistant materials at 1,350 and 1,000° F. (730 and 540° C.). AISI 316 was suceptible to stress corrosion cracking at 1,350° F. (730° C.). Bohlmann and Adamson[55] examine stress corrosion cracking problems in the homogeneous reactor test where austenitic stainless steels are the materials of construction. Preliminary tests showed chloride-induced cracking, but the cracking does not occur in oxygenated UO_2SO_4 solutions unless chlorides are present.

In an examination of the temper brittleness of boron-treated steels by Rosenberg,[56] using fully hardened steels tempered at 650° C., it was found that the introduction of relatively small amounts of titanium through the boron addition agents is sufficient to improve the Charpy v-notch impact properties of the steels. The presence of zirconium does not show similar effects.

Carbon steel, carbon steel weldments, nickel steel, high-strength steel, and high-purity iron were irradiated in the M.T.R. Berggren and Wilson[57] show that neutron irradiation increases the yield and tensile strengths of structural steels but decreases their ductility, possibly changing the behaviour of the steels as materials for structural components. Baldwin[58] examines the irradiation effect at 500 and 700° F. (260 and 370° C.) on tensile and impact specimens of ASTM A302B steel. There appears to be little or no change in the properties. Notched-bend specimens of A201 steel at 300–400° F. (150 and 205° C.) increase in strength but decrease in ductility and energy-absorption ability as irradiation is increased.

Rare Earth Metals.

Trombe[59] summarizes the properties of rare earth metals and examines industrial applications. The following properties of rare earths and thorium are tabulated: formula weight, density, melting point, boiling point, oxide states, ionic radius, normal colour, $H_{vap.}$ (k. cal./mole), $H_{fus.}$ (k. cal./mole), crystal structure, Brinell hardness, compressibility, neutron cross-section and electrical resistance.[60] Barson[61] reports on thermal expansion measurements at temperatures ranging up to 900° C. for polycrystalline samples of lanthanum, cerium, praesodymium, neodymium, gadolinium, terbium, dysprosium, erbium and ytterbium. Lanthanium, cerium, praesodymium and neodymium show plastic flow properties at temperatures well below the melting point. High-temperature phase transformations of praesodymium, neodymium and ytterbium, and the coefficient of expansion for ytterbium, are found to be three times as large as the coefficients for the other metals.

Titanium and Vanadium.

Under certain conditions, during the fabrication and use of titanium, there is a danger of fires and explosions when thin chips are dispersed in air. Peterseim[63] describes the hazards and safety precautions to be taken. The hazards include toxic dangers from certain titanium compounds, alloying ingredients and chemicals used in titanium processing. Makin and Minter[64] describe results of some neutron-irradiation experiments on titanium and zirconium, particularly on mechanical properties. Margolin[65] comments on the value of molybdenum as an alloy addition for titanium at elevated temperatures. A 7% Al and 3% Mo alloy has superior strength-weight properties, and the addition of the molybdenum favourably influences hardenability and oxidation resistance.

Smith and Van Thyne[66] investigated certain properties of vanadium alloys in a preliminary evaluation of their suitability for use as fuel element jacketing materials in sodium-cooled reactor systems. The characteristics of creep and tensile strength, corrosion resistance and thermal conductivity at elevated temperatures studied indicate feasibility.

Zirconium.

A brief summary of the properties of zirconium as a reactor material is given by Paulsen,[67] whilst Pankaskie[68] makes a more detailed analysis of the properties of zirconium, Zircaloy 2, and experimental alloys. Shober *et al.*[69] investigated the tensile and creep properties of zirconium and Zircaloy 2 at temperatures up to 500° C.

Newham[70] outlines a method for purifying zirconium with the object of producing hafnium-free metal for use as a reactor material, and Chubb[71] describes a high strength ternary alloy of zirconium that can be readily

rolled at 800° C. and has four times the creep strength of the pure metal at 500° C. The effect of neutron irradiation on the mechanical properties of zirconium have been investigated by Makin and Minter[64] at a variety of temperatures after irradiation with 5×10^{19}n/sq. cm.

Lustman[72] studies the reactions between zirconium and water, whilst Pemsler[73] discusses the mechanism of oxidation and corrosion of zirconium in terms of diffusion of oxygen and adherence of oxide films. Experiments were made over a temperature range of 400–585° C., and it was seen that the diffusion coefficient of oxygen in zirconium depends on the grain orientation varying by a factor of 2 along different orientations. Oxidation and corrosion rates appear to have a similar orientation dependence.

Bokros[74] reports on investigations made into the effect on the mechanical properties of zirconium of high-temperature liquid sodium. It was found that the surface oxide which develops lowers fatigue life at elevated temperatures, and that only hydrogen has any effect at room temperature in lowering fatigue life. Exaggerated grain growth occurs above 950° F. (510° C.), and reduces fatigue life. Results indicate that zirconium is stable to dimensional changes after thermal cycling.

Domagala *et al.*[75] investigated the transformation kinetics and mechanical properties of Zr-Mo alloys. Alloys containing 1·3, 3·3, 5·4 and 7·5% Mo were prepared using high purity molybdenum and sponge zirconium. The authors established time-temperature-transformation curves based on the resistivity against time-of-anneal curves of isothermally quenched rods. Similar experiments were made on three Zr-Ti and three Zr-Sn alloys based on sponge zirconium prepared by arc melting and forging. None of these alloys qualified as suitable for heat treatment."[6] Bichkov *et al.*[77] have determined certain properties of Zr-Nb alloys, including mechanical properties at room temperature, hot-strength up to 750° C., and hardness measurements after low-temperature ageing treatments. They also established oxidation resistance in air over the range 570–650°C. Bichkov *et al.*[78] report on the measurements that were made for Zr-Nb alloys of Young's Modulus up to 950° C., and at room temperatures after various heat treatments.

Rough[79] analyses the available data on Zr-U alloys in evaluating the behaviour and nature of the alloys as a system, and Lawless *et al.*[80] describe the development of zirconium-clad uranium plates for reactor fuels. Kalish[81] investigated methods for fabricating Zr-U alloys by powder metallurgy techniques, to which the system is amenable: homogeneous alloys can be obtained at all compositions. He obtained densities of better than 97% of theoretical, the alloys having reasonable ductility and high strength. McIntire *et al.*[82] describe investigations into the bonding of uranium and zirconium alloys. Douglass *et al.*[83] determined the transformation kinetics of zirconium alloys containing 8·85, 11·1, 14·3 and 20·7 wt. % U. Dwight and Roebuck[84] report on tests that were made to determine the effects of heat treatment and composition on the corrosion resistance to water at 600° F. (315° C.) of low-uranium zirconium-base alloys: in all, 57 compositions were tested. They found that the most attractive fuel element core alloys were the range of ternary compositions from approximately 0·2–6 wt. % U., and from 2–4% Sn.

Nowikow and Pfeiffer[85] outline the mechanical properties of Zircaloy 2 and the melting and manufacturing processes, and Wheeler[86] describes a method for notch slow-bend testing of Zircaloy 2 with a recording tester that plots bending moment versus angle of bend. It is possible to conduct tests from room temperature to 450° C. by resistance heating the Zircaloy specimens in order to evaluate effects of specimen geometry, temperature and cold work on the fracture characteristics. Bleiberg[87] studied the effects of neutron bombardment at process water temperatures in the MTR upon the properties of Zircaloy 2. There is an increase of 15% in electrical resistivity, whilst notch toughness appears to decrease slightly at lower temperatures and increase slightly at higher testing temperatures. Lemmon[88] reports on studies carried out at Battelle on the reaction between Zircaloy and water at high temperatures. Observations are made on the rate of reaction between solid and molten Zircaloy and steam; spectral and total emissivity of the alloy and its oxide; and the rate of diffusion of oxygen in Zircaloy. McAndrew *et al.*[89] subjected brazements of simple geometry of Zircaloy 2 to corrosion test in 680° F. (360° C.) pressurized water for periods up to 1,200 hours. A large number of experimental alloys as filler metals were used to prepare the test specimens. Some of the specimens survived the test, showing little or no evidence of attack. Mehan[90] presents data obtained from room temperature tensile tests on Zircaloy 3 strips where the thicknesses were 0·065 and 0·185 in.

Liquid Metals.

An interim report on static liquid-metal corrosion tests[91] covering work at Oak Ridge conducted from 1949 to 1952 has been declassified. Molten sodium, lithium, lead and bismuth were tested, mostly at 1,000° C. Sodium was found to be the least corrosive in static and dynamic tests, and almost all alloys showed good corrosion resistance. Lithium attacked the alloys quite severely, especially nickel and nickel alloys. In addition it is susceptive to mass transfer. Lead and bismuth showed similar results, being compatible with very few metals at 1,000° C. Coultas and Cygan[92] attempted to determine the compatibility of sodium, graphite and stainless steel. They investigated corrosion and thermal shock affects, dimensional changes, and penetration of liquid sodium into the graphite pores. Perkins and Slansky[93] report work done on the corrosion of metals and alloys in the sodium process streams of the SIR and STR. Carlander and Hoffman[94] studied the extent to which AISI-C1043 steel is decarburized in certain container materials holding molten sodium, test conditions being 1,000° C. at 400 hours. Carbon transfer was greater when an Armco iron container was used than when a type 304 stainless steel container was used. Saltsburg[95] reports on the reactions of Na-K alloy (78% K) with water vapour. Cordovi[96] describes the preliminary results obtained in a static corrosion test series designed to find suitable construction materials for a proposed liquid fuel power breeder reactor. The most promising combinations of steel and liquid metals for operation at 550° C. appear to be a 2¼% Cr-1% Mo and a 5% Cr-½% Mo-1½% Si steel in U-Bi and U-Bi-Pb (eutectic).

(*to be continued*)

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New Foundry for Precision Casting Steel

Continued from page 31

matter getting inside. Before pouring, the moulds are baked in a gas-fired furnace at a 1,000° C., to ensure that the refractory material is properly converted into a mullite.

Because the refractory covers the pattern in the form of a slurry, the profile of the pattern is accurately reproduced in the mould, and the process has been found invaluable in the making of shapes with intricate contours, such as plastic and extrusion dies. The fact that the metal can be poured into hot moulds, facilitates the production of castings of thinner cross-sectional area than is possible by normal techniques. One of the great advantages of the process is its flexibility and value in connection with development and prototype work. In a number of instances prototypes have been produced from wooden pattern equipment by the Osborn-Shaw process before being transferred to the shell moulding section for bulk production.

The fact that shell moulding is a cheaper process for large-scale production has limited the sphere of activity of the Osborn-Shaw process, but within that sphere there is scope for more extensive use of the process. Castings ranging in weight from a few ounces to between 50 and 100 lb. can be made in quantities varying from one or two off to several hundreds or thousands.

CO_2 Block Process

Briefly, the CO_2 block process consists of mixing a suitable sand with a sodium silicate binder, ramming to shape, and hardening by diffusing CO_2 through the sand mixture. Special sand mixes have been developed to meet the ever increasing demand for accuracy and better surface finish of castings. In components where intricate coring and good surface finish is required, the Osborn-Shaw process has been combined with the CO_2 process.

The process is invaluable for both jobbing work and quantity production, using moulding machines with boxes or snap flasks. The use of fine-grade refractory sand gives a superior finish, but not of the standard associated with the Osborn-Shaw process. A wide range of alloy steels can be cast in these moulds, and in certain instances metal is poured into hot moulds. The process is now to a large extent replacing the Osborn-Shaw process for the development of prototypes, and it has been found suitable for making a number of components which were formerly made by the Osborn-Shaw process.

Wild-Barfield Canadian Office

THE address of the Wild-Barfield Branch Office in Canada has been changed to 77, Grenville Street, Toronto, Ontario. The telephone number remains as hitherto, Walnut 4-2809. In addition to dealing with Wild-Barfield heat-treatment equipment, the Branch is also responsible for sales and service of melting and heat-treatment furnaces made by G.W.B. Furnaces, Ltd., and kilns and lehrs manufactured by the Applied Heat Co., Ltd. This move to more commodious premises will enable the Branch to offer improved service and spares facilities for the growing number of British made Wild-Barfield, G.W.B. and Grafton equipments now operating in Canada.

Steel Wire Production

Darwins' New Kingfield Works

SOME two and a half years ago a new company, Darwins Bright Steels, Ltd., was formed to concentrate the wire producing plants of Darwins, Ltd., and J. Stead & Co., Ltd., under one roof, for greater efficiency of working. The practical outcome of this step was the erection, on the site of an old tip adjacent to the Stead works, of the new Kingfield Works, which were officially opened on June 5th, 1958, by Lord Riverdale.

The works, which has been built by about 90% Darwins labour, has a floor area exceeding 28,000 sq. ft., and the glass area of approximately 14,000 sq. ft. ensures an abundance of natural light. There are five bays, each 112 ft. 6 in. long × 45 ft. wide, the operations conducted in them being : No. 1—heat treatment ; No. 2—cleaning ; Nos. 3 and 4—wire drawing ; and No. 5—finishing. There is an additional brick building attached to the East end, to house the electrical supply equipment and ablution block : there is also an independent building for stocking wire coils, with an adjacent test house for inspection purposes.

The buildings are of steel frame construction, with asbestos roof, brick walls, and roof and side glazing for natural lighting ; the floors are concrete. Artificial lighting consists of ten 400 W. mercury fluorescent discharge lamps and fittings in each bay, which give a general illumination of 18 ft. candles 3 ft. above floor level at night time. Space heating is catered for by radiant gas panels suspended from the roof.

The raw material for the Kingfield Works is supplied by another member of the Darwins Group—Andrews Toledo, Ltd. The steel is made by the open hearth process or in a modern 10 ton Efco-Heroult arc furnace, and is cast into 11¼ cwt. ingots which, when cold, are stripped, examined and dressed. After reheating in producer gas fired continuous furnaces, they are roll cogged to 3 in. square (minimum) billets. After further inspection and dressing, the billets are reheated in oil fired continuous furnaces.

Drawing Equipment

The equipment located in No. 3 bay is for wire drawing: this is mainly cold drawing, but there is one hot drawing machine. The Farmer Norton 9-hole machine is capable of drawing 0·082 in. diameter wire down to 0·042 in. diameter in nine passes or ranges between these sizes and down to 0·018 in. The 4-hole machine by the same maker is suitable for a maximum starting size of 0·212 in. diameter which can be reduced to a finished size of 0·102 in. diameter, depending on the quality of the material. Of the 8 single wire drawing blocks in this bay, two are 22 in. diameter, three 18 in. diameter, and three 12 in. diameter. They are capable of drawing wire of 0·550 in. diameter down to a lowest finishing size of 0·018 in. diameter. The 26 in. hot wire drawing block with infinitely variable speed between 50 and 200 ft./min. through a Heenan and Froude coupling, is for drawing high speed steel wire, which is heated through a graphite bath, baking oven, and lead bath furnace. The size range is 0·330 in. diameter to 0·035 in. diameter.

An important feature of No. 4 bay is a Schumag

Schumag combined drawing machine.

combined drawing machine for drawing, cutting, straightening, and polishing rounds, as well as for drawing, cutting and straightening of squares and hexagons, adapted for iron and steel. The size range is : rounds—0·158 in. to 0·512 in. diameter ; squares—0·158 in. to 0·472 in. across flats ; hexagons—0·196 in. to 0·512 in. across flats. The bar length is 6-12 ft., with a drawing speed of 120 ft./min. and a maximum pull of 6,500 lb. This bay also houses a Crossley 8 hole wire drawing machine.

Heat Treatment

The heat-treatment plant* is housed in No. 1 bay, and comprises a spheroidising furnace, two pit pot annealing furnaces, two pit type vertical cylindrical furnaces, a gas fired coil annealing furnace, and oil and water quench tanks.

An 80 kW. Junkers pit pot vertical cylindrical annealing furnace, originally installed in the Stead Works, is used for annealing, normalising and bright annealing. It will accommodate 26 in. diameter coils and has a pot capacity of 10–12 cwt. Another pit pot furnace by Electric Resistance Furnace Co., Ltd., is rated at 175 kW. and will accommodate coils of 33 in. maximum diameter. It is suitable for bright sub-critical annealing, sub-critical annealing, annealing, and annealing of high speed steel.

For spheroidising—the treatment normally applied to high carbon steel for the purpose of obtaining maximum softness by producing a uniformly distributed globular

* It is hoped to feature a more detailed account of the heat treatment and cleaning plant in the August issue of METALLURGIA.

General view of the heat treatment bay, showing the spheroidising furnace in the background.

condition of the carbide—there is a 350 kW. Electric Resistance Furnace Co., vertical forced air circulation furnace, with a maximum temperature of 800° C., which can deal with 3 ton charges of coils with diameters up to 38 in.

Two further Electric Resistance Furnace Co. pit type vertical cylindrical furnaces, each rated at 120 kW. are used for annealing, normalising, hardening and tempering of carbon steel rod in coil form. Each furnace can treat 22½ tons a week of coils up to 32 in. diameter.

There is also a gas fired annealing furnace, reconstructed by Fuel Furnaces, Ltd., for annealing coils of wire.

Cleaning and Descaling

Bay No. 2 is devoted to the cleaning or descaling of wire and wire rod coils after treatment, and the equipment includes two molten salt baths, for operating the sodium hydride and Efco-Virgo descaling processes, respectively, and a number of pickling tanks.

The sodium hydride plant operates at about 370° C. and uses molten caustic soda, sodium and hydrogen, whilst the Efco-Virgo bath is a patented salt mixture containing activating agents, which operates at a temperature of 500° C. Features of both processes are rapid and uniform descaling, and absence of hydrogen embrittlement and of attack on the base metal. Located between the two baths is a water quenching tank which is fully screened and has pneumatically operated double doors : quenching takes place at sub-floor level.

The seven brick tanks comprising the pickling plant contain hot water, sulphuric acid, hydrochloric acid, nitric-hydrofluoric acid, nitric acid, water (spray) and lime, respectively. The lime serves the dual purpose of counteracting any acid not washed off the wire, and of " holding " the drawing lubricant.

This bay also houses an Electric Resistance Furnace Co., rod baker, which is provided with a system of forced air circulation and is suitable for baking rod in coil form at temperatures of 200°–300° C., with an output of 2–3 tons/hr. with coils up to 42 in. diameter. It can also be used as a preheater for the descaling salt baths.

General view of the finishing and despatch bay.

Finishing

Besides three normal straightening and cutting-off machines capable of handling materials from 0·400 in. diameter down to 0·048 in. diameter and up to 16 ft. in length, there is in No. 5 bay the latest Wafios automatic wire straightening and cutting-off machine incorporating flying shears. This machine has infinitely variable wire feed speed, and is capable of handling wires of brass, copper, phosphor bronze, german silver, etc., in diameter ranging from 0·092 in. to 0·276 in., and high carbon steel wires from 0·092 in. to 0·229 in. with 6 ft. minimum and 13 ft. maximum lengths; the latter figure can be increased by additional straightening extensions.

Other items of finishing equipment include a Robertson reeling machine ; a Schumag centreless grinding and polishing machine, with a range from 0·078 in. diameter up to 0·518 in. diameter ; a Lidkoping No. 2 centreless grinder (with the latest type of Phillips clarifier for swarf separation) which can deal with 0·004–0·800 in. diameter material in lengths up to 10 ft. ; two Scrivener centreless grinders for 0·040–0·500 in. diameter material; and a Canning wire polisher. Two abrasive cutting-off machines, a Speedax and a Ballinger, provide capacity for dealing with material up to 1 in. diameter.

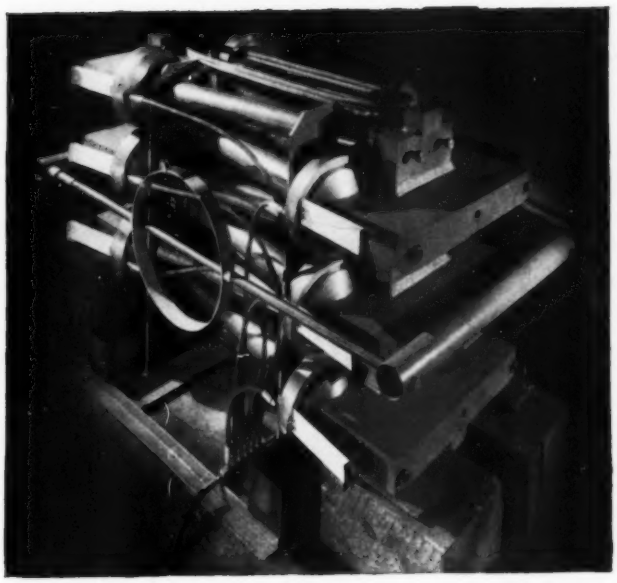
Products

The qualities of steel processed include many of the En and similar specifications, with the addition of low expansion alloys (nickel-iron), heat-resisting wire, silver steel, high speed steel drill rod and carbon chrome drill rod. Apart from the Kingfield Works, Darwins Bright Steels, Ltd., has plant at the Kelham and Millsands Works for processing and finishing heavier material—up to 3 in. diameter.

Continuous Casting Plant for Steel

THE second Schloemann vertical continuous casting plant, designed after the Rossi-Concast system, was put into operation recently at Paderwerk, Gebr. Benteler, Schlob Neuhaus/Paderborn, Germany. This single-strand plant, laid out for a monthly output of 5,000 m. tons, is fed by a 17 m. ton tilting ladle to produce billets 4¾ in. to 6½ in. square, which will later be extended. The billets are cut to lengths of 10–20 ft., and are used for the manufacture of precision seamless steel tubes.

Annual B.W.R.A. Exhibition at Abington Hall



2,000 ton capacity tensile testing machine for brittle fracture studies on welded joints.

THE weather is not a major factor in one's enjoyment of a lecture or a symphony concert, but for garden parties, test matches and open days at multi-building research establishments, rain is definitely taboo. Thus it was that visitors to Abington Hall on the occasion of the British Welding Research Association's Open Day, on June 11th, cast their minds back longingly to previous Open Days, bathed in sunshine, as they watched the rain falling in a steady, relentless downpour. The fact that the Association has been fortunate in its choice of date on previous occasions—one remembers luncheons in the marquee with everyone, not excluding the top table, in shirt sleeves—only served to accentuate the dampness this year. In spite of the weather, however, visitors found much to interest them in the exhibits displayed in the various laboratories, and one can only hope that the grounds quickly recover from the effects of parking cars and tramping feet, as no doubt they will.

The object of the Open Day is to give representatives of member firms an opportunity to obtain a much more vivid impression of what is going on than can be gained from the Annual Report, and to talk to the staff and discuss items of particular interest. Much of the research is of a long term nature which does not lend itself to spectacular exhibits, but close examination of the results obtained in the past year provides a measure of the progress made. It is impossible in the space available to deal adequately with the work in progress, but as it is hoped to deal more fully with certain aspects of it at a later date, no more than a brief outline is given here.

Fatigue

The importance of fatigue failure in all types of structure is stressed by the amount of work being carried out in this field. Among the fusion welded materials being studied are the heat-resisting alloys, exemplified by Nimonic 75; medium strength aluminium alloys; and mild steel. The work on mild steel has been concentrated on establishing data for welds essentially free from defects, which will serve as a basis for studying the influence of internal defects.

The fatigue behaviour of thick-walled pipe containing circumferential welds is being studied under conditions of high internal pulsating pressure in a special purpose machine, and resonance machines are being used for alternating torsion testing of both full-scale shafts and small specimens. In the case of boiler tube plates, comparison is being made between actual fatigue strength values and photo-elastic stress analysis results. The fatigue properties of mild steel shafts reclaimed by welding are of considerable interest, and the effects of pre- and post-heating are among the aspects under investigation.

Metallurgy

Apart from services such as chemical analysis, gas analysis, metallography and the preparation of test pieces, the Metallurgical Laboratory provides facilities for a number of interesting investigations. In a joint research with the Electrical Research Association the arc characteristics of the self-adjusting arc are being studied in the Welding Laboratory, where work is also in progress on high-current inert-gas metal-arc welding of aluminium, and carbon dioxide shielded welding of steel. Other investigations on welding procedure include a study of the hot cracking of Nimonic alloys; the welding of thin gauge deoxidised copper; and the welding of duralumin type alloys.

On the ferrous side, the quantitative effect of hydrogen on heat-affected zone cracking is being studied with the aid of controlled hydrogen contents made possible by gas-shielded metal-arc welding. Tests for heat-affected zone cracking are being explored, and an attempt is being made to explain hot cracking of mild steel weld metal. Some of the conditions contributing towards heat-affected zone cracking when welding alloy steels are simulated by dead load rupture tests carried out

over a period of time, and apparatus has been designed to determine the temperature of formation of cracks in a ferrous weld subjected to a transverse load shortly after welding. Some cracking has been experienced when depositing 12% chromium weld metal, and in view of the possibility that cracking might be related to the high-temperature ductility, slow tensile tests at elevated temperatures have been carried out in vacuum. High temperature, slow fatigue tests have been instituted to investigate the effect of repeated heating and cooling on welds in austenitic steam pipes, and a novel cycling apparatus has been designed to ensure that the shape of the load cycle is representative of what might be encountered in service.

The welding of reactive metals is of increasing importance today, and this is reflected in the work of the Association. A chamber has been designed for making test welds in reactive metals under closely controlled welding and gas shielding conditions. It can be evacuated to 10^{-5} mm. Hg and filled with high purity argon, and experiments have been carried out to determine the effects on the mechanical properties of welds in commercially pure titanium of pollution of the welding chamber atmosphere by small quantities of air.

The factors affecting the gas coverage provided by round nozzles have been investigated. Besides protecting the pool, an additional coverage length is required to protect the cooling weld bead, and an empirical formula for the calculation of this length has been derived. The Argonarc torch has been provided with a specially designed shield to enable titanium to be welded in the open and without contamination of the surface.

Zircalloy 2 is used as a canning material for nuclear reactors, principally because of its excellent corrosion resistance in high-temperature water. Normally, a highly adherent black oxide film develops, but after a critical period of prolonged exposure, a white non-adherent oxide forms, and the corrosion rate increases markedly. Tests carried out in an autoclave to determine the effect of welding variables, have shown that nitrogen picked up in the weld area during welding decreases the time before the onset of the increased corrosion rate.

Brittle Fracture

Work on brittle fracture continues and a feature of the laboratory concerned with these investigations is a 2,000 ton tensile test rig, designed by B.W.R.A. staff and constructed and donated by Babcock & Wilcox, Ltd. This equipment is to be used for tensile tests on welded and notched 3-in. plates. Nearly a hundred tests on 1-in. steel plate have now been performed on the 700-ton tensile test rig, inclusive of maximum loads up to 750 tons, test temperatures down to — 70° C., and 200,000 load applications at up to 400 tons.

A study is being made of the influence of electrode covering, fatigue pre-cracking and stress relieving on the behaviour of welded wide mild steel plate during tensile testing. Welds made by rutile-coated electrodes have shown themselves inferior to the low-hydrogen type. A crack arrest tear test for the study of crack propagation conditions in full thickness steel plates has been developed.

Pressure Vessels

Much of the Association's work on pressure vessels is concerned with branch connections. In this field, the earlier work was concentrated on measuring and calculating the stresses round branches, and on exploring the effects on stress of conventional and experimental reinforcements. In this work, strain gauge equipment has played, and will continue to play, an important part, and techniques have been devised for making possible their use inside water-filled vessels at high pressures. This work has now been extended to study the behaviour of various types of branch design when subjected to fatigue tests on the pulsating pressure plant.

Other work in this laboratory is concerned with the reinforcement of openings in storage tanks. Tests on models have shown that a new design of manhole reinforcement can have a lower stress concentration factor than current designs. In a different field, an extensive programme of experimental stress analysis on pipe branch connections has been completed and a report issued.

Resistance Welding

A study of the fundamentals of spot welding is in progress, with a view to the development of a method enabling the prediction of optimum welding conditions for hardenable steels. This has necessitated a study of the effect of post-welding heat treatment on spot weld ductility, and of methods of measuring the variables involved.

Work elsewhere on ultrasonic welding has prompted the study of pressure welding assisted by lateral low-frequency vibrations, and this work has been carried out in the resistance welding laboratory.

A process recently discovered in the laboratory makes use of the generally undesirable phenomenon of " splashing " in spot welding. By causing molten metal from the weld nugget to splash into a cavity in the electrode, a protuberance of a predetermined shape may be produced already welded to the parent metal.

Structure Testing

Because of its direct relationship with welded structures, the Association has for many years supported the work of Professor J. F. Baker at Cambridge University on the development of the plastic method of designing steel structures. The testing of full scale frames is an essential part of the investigation, and this work is undertaken at the Structures Testing Site at Abington.

New Furnaces for Railway Modernisation

British Railways, Midland Region, have placed an order with Birlec, Ltd., of Birmingham for two electric arc melting furnaces. It is understood that this will be British Railways' first electric melting equipment. The new furnaces will be installed in the British Railways' foundry at Crewe, and will produce 21 tons of high quality steel per day. Each furnace has a nominal capacity of 3½ tons and an electrical rating of 2,000 kVA.

£350,000 Locomotive Order

Yorkshire Engine Co., Ltd., Sheffield, a branch of the United Steel Cos., Ltd., have obtained an order worth £350,000 for the supply of sixteen diesel-electric shunting locomotives to the Port of London Authority. This important order follows the success of six Yorkshire Engine diesel-electric locomotives which have been operating at Tilbury docks for the past year.

NOW I.C.I. OFFERS

electrically heated salt baths

The General Chemicals Division of I.C.I. has recently concluded an agreement with

AJAX ELECTRIC CO. LTD. of Philadelphia

the largest manufacturer of electrically heated salt baths in the world. As a result of this, a range of I.C.I. 'Cassel'/Ajax furnaces heated by electrodes or immersion heaters, suitable for carburising, "cyanide hardening", heat treatment, tempering, martempering, austempering etc., will shortly be available in Great Britain (and a number of overseas territories.)

These electrically heated furnaces have the special advantage of extremely long pot life, of particular value in fully automatic salt bath plants.

The 'Cassel'/Ajax furnace is a notable addition to the wide I.C.I. range of gas- and oil-fired furnaces that have proved so successful over many years.

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'K' MONEL for instance, can be heat-treated to give a tensile strength of 75 tons/sq. in. and a DPN hardness as high as 340. The outstanding strength and hardness of 'K' MONEL have led to its wide acceptance for parts such as pump shafts which often operate under severe mechanical stress in corrosive conditions.

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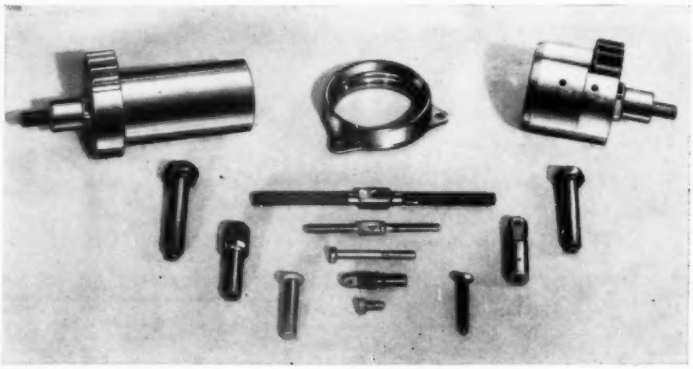
A non-magnetic Anchor Chain link made of 'K' MONEL.



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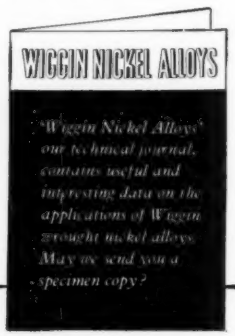
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"Wiggin Nickel Alloys" our technical journal, contains useful and interesting data on the applications of Wiggin wrought nickel alloys. May we send you a specimen copy?

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TGA M/H6

NEWS AND ANNOUNCEMENTS

Investment Founders Technical Association

A NEW technical association serving the investment foundry industry using expendable pattern techniques for the production of industrial metal castings, has been formed under the title of The British Investment Casters' Technical Association. The objects and scope of the new organisation are entirely devoted to technical aspects of investment casting, and will include such activities as the preparation of specifications for materials and testing procedures, the improvement of production techniques, expansion of the application of investment castings, and the general exchange of technical information within the industry.

At the inaugural meeting held in London on June 11th, 1958, which was attended by the representatives of twenty-five companies, the names of the founder member companies were announced as follows: *Full Members*—The Birmingham Small Arms Co., Ltd., Close Tolerance Castings, Ltd., Deritend Precision Castings, Ltd., Firth-Vickers Stainless Steels, Ltd., Hadfields, Ltd., H. & F. Precise Castings, Ltd., D. Napier & Son, Ltd., and P. I. Castings (Altrincham), Ltd. *Associate Members*—Astor Boissellier & Lawrence, Ltd., Chambers Bros., Ltd., Claud Campbell & Co., Ltd., W. J. Hooker, Ltd., Monsanto Chemicals, Ltd., Samuel Osborn & Co., Ltd., Refractory Mouldings & Castings, Ltd., Colin Stewart, Ltd., Wilkins, Campbell & Co., Ltd., and G. L. Willan, Ltd.

The inaugural meeting also elected the following as Members of the Council: MR. D. H. ARMITAGE, P. I. Castings (Altrincham), Ltd., (Chairman); MR. R. W. N. DANIELSEN, Deritend Precision Castings, Ltd., (Vice-Chairman); MR. W. FOYERS, H. & F. Precise Castings, Ltd.; MR. G. A. TOMKINSON, D. Napier & Son, Ltd.; and MR. N. WALKER, Hadfields, Ltd. Through the courtesy of the British Steel Castings Research Association, the address of the newly formed Association will be 5 East Bank Road, Sheffield, 2, and MR. J. BOLTON has been appointed Secretary. It is to him that companies interested in membership should write for further particulars.

Latest Nuclear Metallurgy Research

THE latest research in the metallurgical aspects of atomic energy will be presented at the 1958 International Conference on the Peaceful Uses of Atomic Energy to be held in Geneva, from September 1st to 13th, 1958. The Document Service of The Chronicle of United Nations Activities has inaugurated a complete service to supply the metallurgical industry with materials of the Conference. Available immediately are the lists of papers to be presented, including several hundred papers dealing with metallurgical research throughout the world. Topics covered include the geology and mineralogy of uranium, thorium, beryllium and zirconium deposits; new methods and instruments for prospecting and exploration; processing of pure metals; fabrication of fuel elements including the metallurgy of uranium, thorium, plutonium and their alloys; protection of uranium and thorium miners against internal and external radiation; and methods used in separation of isotopes, including the technology of uranium hexafloride. The lists may be obtained free by writing to: Metallurgy Document Service, The Chronicle of United Nations Activities, 234 West 26th Street, New York, 1, New York.

Lecture Courses

THREE special lecture courses have been arranged by the Metallurgy Section of Kingston Technical College for the session 1958/59.

The first of these deals with "Corrosion and Metal Surface Treatment", and is a one-day-a-week day-time course extending from Tuesday, September 30th, 1958, to Tuesday, March 17th, 1959.

The second course on "Technology of Light Alloys", will consist of six lectures given by a panel of specialists from industry on successive Tuesday evenings from November 11th, 1958, to December 16th, 1958.

The third course on "Metal Surface Treatment Techniques" will again consist of six lectures to be given by specialists from industry on successive Tuesday evenings from February 10th, 1959, to March 17th, 1959.

Further particulars concerning these courses may be obtained from the Engineering Department, Kingston Technical College, Fassett Road, Kingston-upon-Thames.

Documentary Film Directory

MORE than six hundred new documentary films covering an encyclopaedic range of subjects become available each year, and most of them can be borrowed by responsible organisations, without charge. Although there are now some hundreds of industrial and institutional film libraries, there is not—as yet—a comprehensive directory which those who wish to borrow films can consult. The journal *Film User* is hoping to provide such a directory, and, to make it as complete as possible, the Editor would be glad if organisations or firms with films to lend would get in touch with him at 319, High Holborn, London, W.C.1 (Tel. Chancery 5238), unless they have already received a questionnaire.

Non-Destructive Testing Summer School

A SUMMER SCHOOL on the Principles and Practice of Non-Destructive Testing, intended to benefit senior and chief inspectors from industry, is to be held in Manchester from September 8th–12th, 1958. This Summer School has been sponsored by the British National Committee for Non-Destructive Testing, and is being organised by the Manchester College of Science and Technology, the Manchester Association of Engineers, and the Institution of Engineering Inspection. The Organising Lecturer is Dr. J. H. Lamble of the Manchester College.

In designing the course, it is expected that those attending will have some basic knowledge of non-destructive testing techniques, and the physical background, with interpretation of test results, will be dominant themes. In addition to lectures on the theory and practice of the various non-destructive testing techniques, there will be talks on statistical quality control, on the economics of non-destructive testing, and on the collection of data. There will also be laboratory demonstrations of test equipment and a visit to a large

works where non-destructive test methods are employed.

Accommodation for those attending will be provided in the residential quarters of Hulme Hall, and the lectures will be held in the Mechanical Engineering Department of the Manchester College of Science and Technology. The total cost of the course is expected to be approximately £18, and as capacity is limited, it is advisable to make early application for places. Further particulars can be obtained from the Registrar, The Manchester College of Science and Technology, Manchester, 1.

International Nuclear Energy Course

Two international training courses are being organised by the European Nuclear Energy Agency to enable senior technical executives to increase their knowledge of the technical, economic and industrial aspects of nuclear energy. Each of these courses will have facilities for some thirty participants from O.E.E.C. countries, and will consist of lectures on problems in physics, chemistry, electronics, metallurgy and mechanics related to the construction and operation of reactors, as well as on preparation and chemical processing of fuels. The programme is designed to allow time for discussion, and will comprise numerous experiments and visits to installations.

A first course in French will be held with the help of the French Atomic Energy Commissariat from July 15th to 25th at the Nuclear Research Centre of Saclay (France). A second course in English will take place from August 18th to 29th at the recently opened Netherlands-Norwegian Reactor School, attached to the Joint Establishment for Nuclear Energy Research (JENER) at Kjeller (Norway). Enquiries for information should be sent to competent national bodies, or to the European Nuclear Energy Agency, O.E.E.C., 2, rue Andre Pascal, Paris, 16e.

Mineral Processing Congress

THE Institution of Mining and Metallurgy will hold an International Congress on Mineral Processing in London from April 6th–9th, 1960. It is proposed that the papers to be discussed should cover fundamental and applied research and development in the fields of mineral dressing, chemical processing, roasting, cyanidation, leaching and solvent extraction, but not smelting. Enquiries should be addressed to: The Secretary, The Institution of Mining and Metallurgy, 44, Portland Place, London, W.1.

New S.L.A. Translation Service

THE Special Libraries Association Translation Centre, located at the John Crerar Library in Chicago, has announced that it can now furnish, on a subscription basis, printed catalogue cards for current scientific and technical material which has been translated into English from all languages, including Russian. This latest effort of the Centre to facilitate the exchange and growth of scientific knowledge in the Western World will make available in easy-to-use, up-to-date card form the thousands of citations given in the Centre's bibliographical journal, *Translation Monthly*. Four types of subscriptions to translation catalogue cards are available:

(1) Full coverage of *Translation Monthly* (approximately 12,000 titles yearly).
(2) Coverage of all translations currently received by the Centre (approximately 6,750 titles yearly).
(3) Coverage of all Russian translations received by the Centre (approximately 3,100 titles yearly).
(4) Coverage of all titles in specific subject fields.

Further information about the S.L.A. Translation Centre and its services can be obtained from the Centre, at the John Crerar Library, 86, East Randolph Street, Chicago 1, Illinois, U.S.A.

Aero Research Name Change

AERO RESEARCH, LTD., Duxford, Cambridge, announce that the name of the company has been changed to CIBA (A.R.L.), Ltd. Aero Research was formed in 1934 to pioneer research into aircraft structures, including the development of new adhesives. In the last twenty years the range and extent of the Company's activities have radically changed, and its Duxford factory is now one of the foremost suppliers of synthetic resin adhesives in the United Kingsom, with products used in every major industry. Today, it is stated, the name of Aero Research is no longer appropriate, and the time has come to introduce a new name not inconsistent with the Company's present activities. This name has associations with the past but emphasizes affiliation to the world-wide CIBA organisation. The trade names of Aerolite, Araldite, Redux, and other proprietary products are unaffected.

Open General Licences for the Export of Metal Goods

THERE is a control over the export of certain aluminium, copper and iron and steel goods to ensure that scrap metal is retained in the United Kingdom. In this connection the Board of Trade announce that the Open General Licences which authorise the export of certain aluminium, copper, and iron and steel goods valued at more than £240, £350 (and of certain copper alloy goods valued at £240 per ton) and £35 per ton, respectively, are being revoked, and replaced by new Open General Licences which lower this value limit as follows: aluminium goods to £220 per ton; copper goods to £300 per ton and the value of any alloy mainly of copper in any goods to £200 per ton; and iron and steel goods to £25 per ton. The goods are those specified in Group 6(2) of the First Schedule to the Export of Goods (Control) (Consolidation) Order, 1958. Enquiries about these licences should be made to the Export Licensing Branch, Gavrelle House, Bunhill Row, London, E.C.1 (Tel.: Monarch 4071). Copies of the Open General Licences (price 3d. each, by post 5d. each) may be obtained from H.M. Stationery Office.

Corrections

WE regret the following errors in the June issue:—

A REVIEW OF DIFFUSION IN ALUMINIUM.

In the first column of page 273, the formula—
$D = De_0^{-Q/RT}$ should be $D = D_0e^{-Q/RT}$

RECENT HEAT-TREATMENT FURNACE INSTALLATIONS.

Acknowledgment for Fig. 6 on page 285 should be made to Brayshaw Furnaces and Tools, Ltd., and not to Metalectric Furnaces, Ltd.

Personal News

THE UNITED STEEL COS., LTD. announce that LT.-CDR. G. W. WELLS, D.L., at present Managing Director (Engineering Works), has been appointed Managing Director (Production), responsible to the General Managing Director, MR. A. J. PEECH. Commander Wells will continue to hold the position of General Manager of Appleby-Frodingham Steel Company, a Branch of United Steel. Following this appointment, MR. A. JACKSON will relinquish his position as General Works Manager of Appleby-Frodingham as soon as possible in order to take up a new appointment as Technical Adviser on Steelmaking for United Steel, responsible to Lt.-Cdr. Wells. He will retain his Directorship of Appleby-Frodingham but will become Technical Director of that Company. Mr. Jackson will also join the boards of the other three steelmaking companies in the group—Steel, Peech & Tozer, Samuel Fox & Co., Ltd., and Workington Iron and Steel Company. Mr. J. D. JOY will relinquish his position as General Works Manager at Samuel Fox on August 31st and will move to Appleby-Frodingham as a Director and General Works Manager, with a view to becoming Deputy General Manager on January 1st, 1959.

DR. W. A. BAKER, Research Manager of the British Non-Ferrous Metals Research Association, is leaving at the end of July to join Northern Aluminium Co., Ltd. To fill the vacancy arising from his resignation, the B.N.F.M.R.A., has appointed MR. A. CIBULA and MR. R. EBORALL—respectively Heads of the Melting and Casting and of the General Metallurgy Sections—as Research Superintendents, jointly responsible to the Director for the work of the Research Department.

BRIGADIER A. LEVESLEY, a Director of EDGAR ALLEN & CO., LTD., has been elected President of the Sheffield and District Engineering Trades Employers' Association, in succession to MR. AMBROSE FIRTH.

MR. T. W. RUFFLE, has left the E.N.V. Engineering Co., Ltd. After some weeks in the U.S.A., he will be setting up a British office for Ipsen Industries Inc. of Rockford, Illinois. This will establish sales and service facilities here for the Ipsen automatic atmosphere heat treatment furnaces and accessories, atmosphere generators and atmosphere control instruments, which are now available on the European market.

THE ENGLISH ELECTRIC CO., LTD., announces that SIR ARCHIBALD FORBES, G.B.E., has been elected a member of the Board of Directors. Sir Archibald, who has had a long and distinguished record in Government service, is Chairman of the Iron and Steel Board.

VICE-ADMIRAL SIR FRANK MASON, K.C.B., has been appointed to succeed SIR ANDREW MCCANCE, F.R.S., as Chairman of the Mechanical Engineering Research Board.

THE BRITISH ALUMINIUM CO., LTD., announces that MR. J. W. BENNETT, lately President of Atomic Energy of Canada, Ltd., has been appointed General Manager of the Canadian British Aluminium Co., Ltd., in succession to MR. P. T. ENSOR, M.B.E., who is returning to the United Kingdom in July to take up other duties with The British Aluminium Co., Ltd.

TECHNICAL DESIGNS, LTD., have appointed MR. P. B. WARD as Sales Manager. Prior to this appointment, Mr. Ward was Sales Manager of Danite Hard Metals, Ltd., of Doncaster, and was previously with Deloro Stellite, of Birmingham.

MR. H. E. HILL, has been appointed Deputy Chairman of Darwins Group, Ltd.

MR. J. E. CLARK has been appointed Manager of the Midlands District for British Oxygen Gases, Ltd., in succession to MR. J. G. WILLIAMS, who has retired after 46 years' service.

MR. H. W. BOYNE has now joined Colloidal Graphite, Ltd., of London and Sheffield as Technical Sales Representative. Until recently Mr. Boyne was Home Sales Manager of Arthur Balfour & Co., Ltd.

METROPOLITAN-VICKERS ELECTRICAL CO., LTD., announces the appointment of DR. L. W. BROWN, as Assistant Chief Electrical Engineer (Light Current), in addition to his present duties as Chief Engineer, Electronics Department.

SAMUEL FOX & CO., LTD., a subsidiary of The United Steel Cos., Ltd., announce that MR. E. HAMPSHIRE, Technical Superintendent, Spring Manufacture, has been appointed Production Controller. He succeeds Mr. D. A. HOPKINS, who is joining United Steel's Department of Operational Research and Cybernetics. MR. A. ASPINALL, formerly Assistant Manager of the Laminated and Coil Spring Departments, is appointed Liaison Engineer (Springs).

Obituary

WE regret to record the death of MR. W. H. EISENMAN, Secretary and a Founder Member of the American Society for Metals, who died on Friday, May 30th, in a LaJolla, California hospital, at the age of 73.

A native of Jamestown, Ohio, Mr. Eisenman joined the American Society for Steel Treating, forerunner of the A.S.M., in 1918 as National Secretary. Under his leadership the Society grew from a one-desk organisation with fewer than 200 members to more than 30,000 members in 105 Chapters in the U.S. and Canada. His thousands of friendships in the metalworking industry were made during his long service as Managing Director of the National Metal Show, one of the nation's largest industrial expositions. He also directed the Western Metal Exposition and Congress biennially at Los Angeles, for twenty years, and shortly before his death had launched the new Southwestern Metal Exposition and Congress, at Dallas, Texas.

Mr. Eisenman's contacts were world-wide, and he was originator and Secretary General of the first World Metallurgical Congress at Detroit in 1951 and of the second Congress at Chicago in 1957 : both drew metals scientists from 40 countries. He was an Honorary Member of Die Deutsche Gesellschaft für Metalkunde (Germany), Societe Francaise de Metallurgie (France), Association des Ingenieurs Sortis de l'Ecole de Liege (Belgium), and the Iron and Steel Institute (Great Britain). In 1956, Mr. Eisenman was awarded the A.S.M.'s Gold Medal for distinguished contribution to metallurgy, and at the time of his death, he was scheduled to receive an honorary Doctor of Laws degree from Western Reserve University, Cleveland, Ohio.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Argonarc Power Unit

A COMPOSITE power unit which is designed for use with the Argonarc welding process is now being marketed by the Industrial Division of British Oxygen Gases, Ltd. Known as the CPU 350, this compact and mobile unit is said to provide maximum productive efficiency when used in connection with the A.C. welding of aluminium and its alloys up to $\frac{3}{8}$ in. in thickness in a single pass, and the welding of stainless steel up to $\frac{1}{8}$ in. in thickness.

A remote control foot switch, coupled with automatic arc starting and control of both argon and water enables welding speed to be increased. After the unit has been switched off, the electrode cools in the protecting argon envelope, the gas continuing to flow automatically for a pre-determined period. This results in economy of gas and ensures that the cleanliness of the electrode is maintained.

The unit incorporates surge injection, which is the introduction into the arc of a D.C. pulse, timed to coincide with the beginning of the oxide scavenging positive half cycle only. It is of sufficient magnitude to cause the arc to ignite immediately and thus provides a full positive half cycle. Surge injection allows a substantial reduction of open circuit voltage, resulting in a lower transformer rating, together with a reduction in the amount of current taken from the mains. Since the H.F. starting spark is only present at the start of the welding operation, radio and television interference is confined to this period and is entirely eliminated during actual welding. With the D.C. suppressor unit, an equal positive and negative half cycle of welding current is ensured, giving welds which are clean and bright.

The composite power unit is suitable for 360/500 V. 50 c./s. single-phase operation, with a striking voltage of 50 V. Rating is 10·75 kVA. continuous, or 17·5 kVA at 0·5 duty cycle. Welding current is 25 to 350 A. and 215 A. continuous.

British Oxygen Gases, Ltd., Industrial Division, Spencer House, St. James's, London, S.W.1.

Humidity Test Cabinets

BARLOW-WHITNEY have recently added to their range of humidity cabinets three new models. Designated HTC 5, 6, and 7, they are all 36 in. high × 36 in. deep, internally, with widths of 36, 54, and 72, respectively. They meet the demand for increased capacity for subjecting intermediate and larger electrical, electronic and telecommunication components and assemblies, samples of packaging, plating and protective finishes, etc., to the tests specified in the appropriate specifications.

The cabinets are self-contained units, and only require connection to electricity and water supplies and provision for drainage. The interior is constructed of heavily tinned copper which has excellent thermal and corrosion resisting characteristics. The control system caters for temperatures from ambient to 100° C., and relative humidity conditions from 40% to 99% can be produced with temperatures up to 70° C. Provision is also made for controlled cyclic temperature variation under damp heat conditions adjustable for both amplitude and frequency. Particular attention has been paid to the air circulator to ensure that uniform distribution of temperature and humidity prevails.

Other features include large viewing windows and interior inspection lighting, and convenient holes for test leads which can be sealed effectively by rubber inserts when not in use. Optional features include time switch, two-pen recorder, and ultra-violet irradiation device. These cabinets are also available to special order incorporating refrigerator equipment for operating down to approximately 0° C.

Barlow-Whitney, Ltd., 2, Dorset Square, London, N.W.1.

Molten Metal Tapping Valve

SKLENAR FURNACES, LTD., have recently developed a molten metal tapping valve primarily intended for use with aluminium and its alloys. When fitted to a furnace the new valve can control the flow of metal through a varying range from 250 lb./hr. to a maximum throughput rate of approximately 10,000 lb./hr. The illustration shows the valve under test for intermittent operation: over 2,000 complete cycles were achieved before the replaceable seals had to be renewed. At the end of this test the valve showed no signs of erosion.

The valve is now being fitted to large Sklenar aluminum melting/holding furnaces supplying a constant stream of metal to continuous strip casting mills. Developments are proceeding with the intention of extending the range of alloys for which the valve can be used, and it is hoped that it will later be possible to use the design for copper and copper-base alloys.

This new development enables the equivalent of a lip-axis pour to be achieved with a non-tilting furnace, so that larger capacity furnaces can be used, with resultant saving in the initial capital outlay. Furthermore, the metal can be tapped beneath the oxide film covering any bath of molten aluminum, diminishing considerably the danger of oxide inclusions.

Sklenar Furnaces, Ltd., 385 *Newport Road, Cardiff.*

Pulsaire Dust Collector

THE only major improvement in the field of dust collection for over a decade is the claim made for the new Mikro-Pulsaire collector, an American machine which is now manufactured under licence in this country and marketed by Pulverizing Machinery, Ltd., of Fishponds, Bristol. The main advantage of this dust collector is the complete absence of internal moving parts. It uses a method of continuous air filtering of powder and dusts which dispenses with the need for mechanical systems of filter cleaning.

The dust-carrying air passes into cylindrical filter elements composed of woollen and synthetic felts, 4 ft. or 6 ft. long, leaving the dust to fall from their external surfaces to be collected at the bottom of the pressure cabinet. Instead, of using mechanical methods, the Pulsaire clears the filter cloths by periodical high pressure air currents in the reverse direction to the filter flow, i.e., from inside the cylinders. Above the opening in the head of each cylinder is a nozzle connected to a compressed air supply at 60 lb./sq. in. through a solenoid control valve. An electrical timer opens each valve in sequence for whatever period and frequency is desired—for instance, 0·1 second every 10 seconds. The contoured design of the cylinder openings brings about Venturi action and induces a secondary flow of sufficient volume and pressure to clear the filter cloths against the filter flow pressure. The dust adhering to the outside of the filters is literally blown away before it is thick enough to impede the rate of collection.

One of the principal advantages claimed for the Pulsaire system is that it needs practically no maintenance. The employment of compressed air instead of mechanically moving parts—shakers or blow rings with their attendant chains, sprockets and bearings—enables the unit to operate for long periods at a time without attention. Abrasive and toxic dusts present no particular difficulty, the former because there are no moving parts to be damaged, and the latter because the cabinet seldom needs to be opened for inspection.

Pulverizing Machinery, Ltd., Fishponds, Bristol.

Vertical High-Frequency Motor-Alternator Set

A NEW type of vertical, medium rating (75–300 kW.) high-frequency generating equipment for induction heating and melting applications at a frequency of 8·7 kc./sec. has been introduced by B.T.H. The new set, being arranged for vertical operation, occupies far less space than a normal horizontal machine of the same rating. Furthermore, it is very quiet in operation.

The first set to be manufactured has an output of 75 kW., 8·7 kc./sec. It comprises a heteropolar inductor alternator and a squirrel-cage induction motor—the motor being mounted vertically above the alternator. The frame and the shaft are mounted on the bottom end-shield and the set is supported on four resilient mountings. The set is totally enclosed inside sheet metal covers, which can easily be removed, and is cooled by two water coolers, one being placed in the alternator stator core and the other wound spirally round the motor frame.

B.T.H. can also offer a similar vertical set of a higher rating, and sets will shortly be available at 3 kc./s. and 8·7 kc./s. with approximately double the output of the present machine. Under suitable conditions, these high-frequency alternators may be operated in parallel to supply higher powers than can be generated by a single unit.

The British Thomson-Houston Co., Ltd., Rugby.

CURRENT LITERATURE

Book Notice

WEIGHING, LABORATORY TECHNIQUES

By H. Ulbricht, Ebingen. One of the " Dechema-Erfahrungs-austausch pamphlets, 125 pages, duplicated typescript with 42 illustrations. Price DM. 50 (to members of Dechema DM. 40).

THE aim of the " Dechema-Erfahrungsaustausch " is to avoid unnecessary duplication of work and to present the results of proven experience in a clear and simple manner, which has been fully achieved in this pamphlet. It gives a review in the shortest and most concise form of all the types of balances which are used in laboratory techniques, starting with the technical balance with a relative weighing error of $\pm 10^{-3}$g. up to the precision balances required in research laboratories with a sensitivity of 1 microgram. The pages dealing with the various types of balance are particularly instructive, as they facilitate a comparison between individual models in regard to methods of construction and degree of accuracy. A detailed definition of the terminology and the symbols used in formulae bear witness to the constant efforts made by the DECHEMA to achieve uniform methods of designation. This pamphlet represents a valuable contribution which will be welcomed by all who are concerned with weighing techniques.

Trade Publications

A leaflet recently issued by Monometer Manufacturing Co., Ltd., features a hydraulic tilting truck molten metal transfer ladle which has been developed by the company for transporting the molten metal from the melting unit to the foundry, and for feeding holding furnaces for die-casting. Lifting and tilting is by a double-action pump and the former is adjustable to suit various pouring positions. It is available in capacities of 200, 300 and 400lb. for light alloys, and 150, 250, 400 and 600 lb. for copper-base alloys, etc.

MUCH of the essential research and development work associated with introducing titanium to the chemical industry has been carried out by I.C.I. Metals Division, who three years ago pioneered the commercial production of wrought titanium in this country and now operate Europe's largest titanium melting and fabricating plant. In the course of their extensive research programme, they have made several notable contributions to titanium technology, and the latest of these is described in a new I.C.I. leaflet. Anodically protected titanium carrying a small impressed voltage can now be considered for use in some of the most difficult situations with which chemical engineers are faced. Typical environments for which titanium can now be seriously considered as a material of construction are hot strong sulphuric, phosphoric, hydrochloric, oxalic and formic acids.

ISSUE No. 130 of *Foseco Foundry Practice* contains an article on degassing developments, tracing the history from gaseous techniques. through various methods involving the use of solid degasifying agents and a plunger, to their latest development, a solid agent which needs no plunger as the tablet is internally weighted. Other features deal with ladle and spout additions to molten cast iron ; the investigation of the failure of gunmetal test bars ; and a number of hints and tips on various aspects of foundry practice. Copies may be obtained from Foundry Services, Ltd., Long Acre, Nechells, Birmingham, 7.

A new brochure emanating from The Telegraph Construction and Maintenance Co., Ltd., presents in a concise form particulars of a wide range of products made by the company. These include cables of all types ; special metals, such as beryllium-copper, controlled expansion alloys, resistance alloys, and alloys having a wide range of magnetic permeabilities, resistivities and saturation inductions ; plastics such as polythene and gutta percha ; and cableship equipment.

THE Spring 1958 issue of the Copper Development Association's new magazine *Copper* opens with a reference to the work of the Copper Development Directors' Committee in making Europe copper conscious. Articles featured in this issue deal with the use of copper in brewing ; mineral insulated copper cables ; central heating radiators ; copper welding ; electronic telephone equipment ; a strip mill with automatic gauge control ; and brasses—an item in a series on copper and its alloys.

AN outstanding feature of the April issue of *The Nickel Bulletin* is an extended abstract of a paper which will be regarded as a miniature handbook on the electroplating of nickel and its alloys : three tables contain much useful reference data. Reference is made in other abstracts to new electroless and electroplating processes. The growing importance of powder metallurgy in industry is reflected by papers contributed to an international symposium on the subject, and by abstracts of literature relating to production and uses of sintered nickel-containing stainless steels and alloys. Other items dealing with heat and corrosion-resisting materials include a paper on the machining of high-temperature alloys (recommendations to nickel-base alloys are summarized in easy-reference form) ; recent specifications for nickel-containing materials ; and papers listing some of the applications of corrosion-resisting materials in the chemical industries. In connection with constructional steels, an abstract of unusual interest summarizes information on methods of extracting and examining microconstituents in steels. Other items in this issue are concerned with investigations of the structure and physical properties of nickel and its alloys, and the issue also contains the first quarterly patent review of the year.

" THE NUCLEAR POWER STATION " is the title of a new booklet just published by Wakefield-Dick Industrial Oils, Ltd. The purpose of the booklet is three-fold : first to highlight the importance to British industry of the development of nuclear power ; second to explain the structure of the nuclear power industry as at present constituted ; and third to illustrate the way in which a nuclear power station differs physically from a conventional station. Wakefield-Dick have already been appointed supplier of lubricants and transformer oils to several nuclear power stations.

LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

JULY, 1958. Vol. LVIII, No. 345

Determination of Carbon in Titanium, Zirconium and Their Alloys by Gravimetric and Conductimetric Methods

By D. F. Wood and M. Williams

Research Department, Imperial Chemical Industries, Ltd., Metals Division, Kynoch Works.

Carbon in titanium and zirconium can be satisfactorily determined by a combustion method involving the use of argon to moderate the otherwise vigorous oxidation reaction, provided that suitable fluxes are mixed with the sample. The final stages in the analysis can be carried out either gravimetrically or conductimetrically.

PUBLISHED methods for the determination of carbon in titanium[1, 2, 3] are based on oxidation of the sample in a stream of oxygen, the evolved carbon dioxide being absorbed in soda-asbestos and weighed. Normally the gravimetric method is suitable for the determination of carbon down to about 0·05%, and has a precision of about ±0·01%. However, unless extreme care is taken, low and variable carbon values are obtained due to retention of carbon by the slag formed during vigorous, and some times uncontrollable oxidation of the metal. Recommendations differ with regard to the type of flux and working temperature required to overcome this difficulty, and accuracy of the method is impaired by the restricted sample weight that can be taken. This limitation precludes application of the carbon procedure applied to steels,[4] in which a large sample weight (16g.) is used.

Improvements in the manufacture of titanium and zirconium, notably replacement of graphite electrodes by consumable metal electrodes in the arc-melting process, have led to the production of material with carbon contents below 0·05%, and a more accurate analytical procedure was therefore required.

This paper deals first with an investigation into the relative merits of various fluxes and the advantage of using argon to moderate the otherwise rapid oxidation of titanium and zirconium; subsequently, application of a conductimetric method[5] to the determination of small amounts of carbon in these metals and their alloys is described.

TABLE I.—CARBON IN STANDARD REFERENCE STEELS.

B.C.S. Steel No.	Carbon %	
	Certificate Value	Determined Gravimetrically
152	0·114	0·110 0·110 0·110
237	0·083	0·085 0·081
152/1	0·07	0·073 0·065 0·064

Experimental

Combustion Train

The combustion train used was essentially conventional in design, and to ensure that it was in a satisfactory working condition, reference steels were examined by a standard gravimetric procedure using a relatively large sample weight. Table I shows the satisfactory results obtained.

Fluxes

Various fluxes have been recommended as a means of assisting complete oxidation of titanium. These include tin,[1] lead,[2] a mixture of copper, tin and iron,[3] and a mixture of copper, tin and lead.[6] For zirconium, tin and iron have been recommended[7] as individual fluxes. Various working temperatures between 900° C. and 1,200° C. have also been recommended.

In view of conflicting claims as to the best choice of flux and working temperature, experiments were made to establish optimum conditions for complete oxidation of the metals under consideration.

Blanks

A good flux, in addition to obvious qualities, should provide a low and reasonably consistent blank value. For the determination of carbon below about 0·05%, a blank value of about 0·2 mg. (equivalent to 0·005% C using a 1 g. sample), is permissible.

Blank determinations were made at a temperature of 1,150° C., using calcined combustion boats and 2 g. samples of each of the following materials; copper (drillings), tin (powder), lead (powder), lead dioxide, iron (powder), manganese (chips) and nickel (powder). Only copper and tin gave values less than 0·2 mg. Copper, however, severely attacked the combustion boat. Of the remaining fluxes, lead gave the lowest blank value, 0·5 mg./2 g., and this was subsequently reduced to about 0·1 mg./2 g. after melting the powder and using drillings from the rapidly cooled solidified melt.

Copper, tin and lead fluxes were used separately in further experiments.

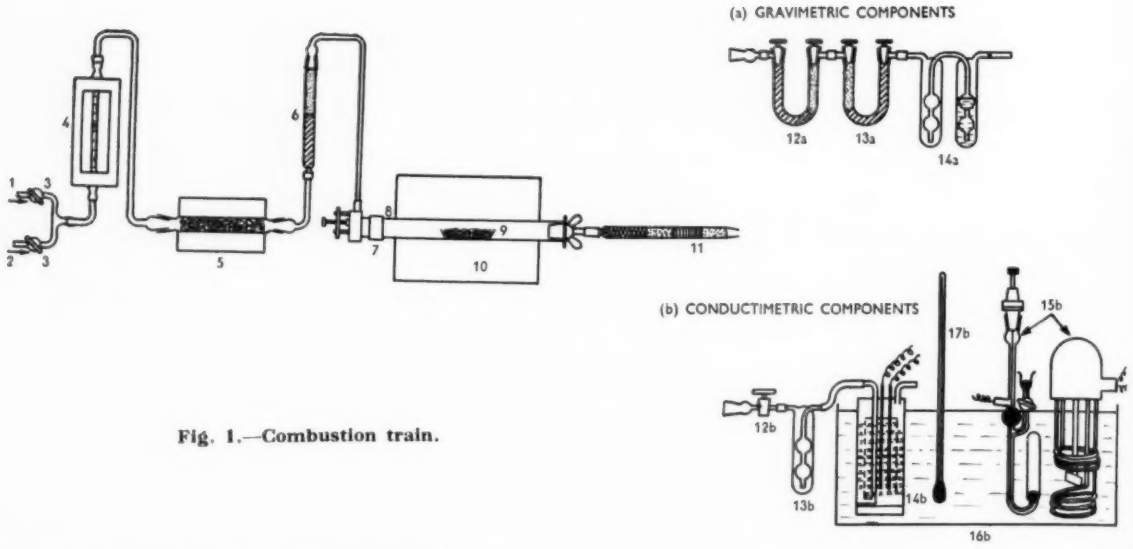

Fig. 1.—Combustion train.

Oxidation of Titanium or Zirconium in the Presence of Copper, Tin and Lead.

The rate and extent of oxidation are largely dependent on the physical nature of the samples, and tests were made on both fine and coarse turnings of titanium and zirconium. Samples (1 g.) were heated at 1,150° C. in an atmosphere of oxygen with 2 g. of copper, tin or lead.

Titanium, in the form of fine turnings, oxidised readily in the presence of each of the three metals, but only lead had any appreciable fluxing action. Tin accelerated the reaction, and copper again severely attacked and occasionally penetrated the combustion boat. With coarse turnings, complete oxidation was obtained only in the presence of lead. Using this flux, carbon values were reproducible to within about $\pm 0{\cdot}01\%$ as shown in Table II.

In tests with zirconium at 1,150° C., tin and lead were unsatisfactory as fluxes; incomplete oxidation was obtained on both fine and coarse turnings. Copper acted as a flux to some extent, but due to severe attack on the combustion boats, tests were discontinued. Further tests were made using tin, lead, iron, manganese and nickel at temperatures ranging from 1,050° C. to 1,250° C., but complete oxidation was not achieved in any of these experiments.

In the absence of a satisfactory flux for zirconium, attempts were made to achieve complete oxidation by moderating the reaction, first by means of alumina and subsequently by using argon. A preliminary note on the use of argon for this purpose has already been published by this laboratory[8].

TABLE II.—GRAVIMETRIC DETERMINATION OF CARBON IN TITANIUM USING LEAD FLUX.

Material (1 g. samples)	Carbon (%)
C.P.* Titanium (Low carbon)	0·016 0·013 0·022
371 Titanium Alloy (No. 1) (12½%Sn/2½% Al)	0·019 0·021 0·015
314A Titanium Alloy (No. 1) (4% Al/4% Mn)	0·024 0·038 0·018

* Commercially pure.

ALUMINA MODERATOR

Fine drillings of zirconium were mixed with calcined alumina in a combustion boat, and the charge was covered with a layer of alumina before oxidation at 1,150° C. This was successful in delaying initiation of the reaction, but oxidation, though less vigorous, was sporadic, and samples were not completely oxidised.

ARGON MODERATOR

Tests were made in which the combustion train was first filled with argon which, after introducing the sample into the combustion tube at 1,150° C., was replaced by oxygen at a flow-rate of about 80 ml./min. Oxidation of 1 g. samples of both fine and moderately coarse turnings of zirconium and Zircaloy 2 (1·5% Sn, 0·12% Fe, 0·10% Cr, 0·05% Ni) samples proceeded smoothly, and reproducible results were obtained.

It was noted, however, that consistent results of about 0·16% carbon were obtained on a sample of zirconium which had previously given a value of 0·22% carbon in the presence of copper (without argon as moderator). Further tests in the presence of copper (using argon as moderator) confirmed the carbon content of this sample to be about 0·22%, showing that a flux is necessary to obtain quantitative results. (Attack on the combustion boats was rendered less significant by using boats with a thicker base.)

Subsequently, tests were made (with argon as moderator) using 1 g. of zirconium with separate 2 g. amounts of tin, lead, bismuth, iron, nickel or cobalt and with binary mixtures of these fluxes. A mixture of 2 g. of iron and 1 g. of bismuth was considered the best flux, and consistent results of about 0·22% were obtained on the zirconium sample. It was noted that the fluxing action of many of these metals is considerably improved in the presence of argon as a moderator.

This controlled oxidation procedure was applied to titanium, but samples of moderately thick turnings were only completely oxidised in the presence of lead. Use of argon had an advantage, however, in eliminating the initial vigorous oxidation and in facilitating control of reaction, thus making it possible to oxidise up to about 4 g. samples (with 3 g. of lead).

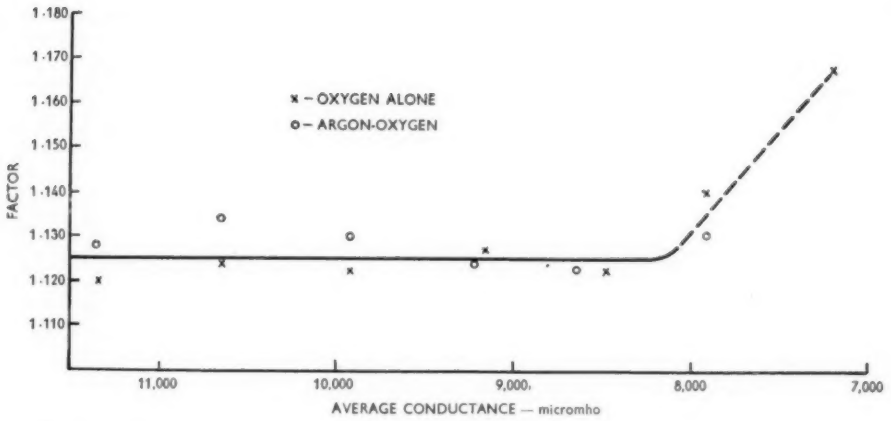

Fig. 2. — Calibration graph (temperature of cell thermostat 25·00 ± 0·02° C.).

To effect complete oxidation of larger weights of zirconium, it was necessary to moderate the oxidation still further. Thus, after introducing the sample (plus flux) into the argon-filled combustion tube, the argon supply was adjusted to about 25 ml./min. and combined with an oxygen supply of about 80 ml./min. This mixed gas was supplied to the combustion tube for 5 min., then oxygen alone was supplied at a rate of about 80 ml./min. until all carbon dioxide was collected in the absorption tube.

Using this procedure the reproducibility of carbon results, using 4 or 3 g. of titanium or zirconium respectively, was within ±0·005% as shown in Table III.

Application of Conductimetric Procedure

The apparatus used is shown schematically in Fig. 1*b* and essential details of components are included in the Method. The temperature coefficient of conductance is about 2%/° C. and, in order to obtain satisfactory reproducible results, the conductivity cell is immersed in a thermostatically controlled water-bath (25° ± 0·02° C.).

The factor for converting change in cell conductance, due to absorption of carbon dioxide, into micrograms of carbon, was determined by applying the conductimetric procedure, with argon moderator and lead flux, described in the Method, to samples of a British Chemical Standard (B.C.S.) steel No. 239/1 (certified carbon content 0·32%).

$$\text{Factor} = \frac{\text{carbon (\%)} \times \text{sample weight (g.)} \times 10^4}{\text{micromhos change}}$$

TABLE III.—GRAVIMETRIC DETERMINATIONS OF CARBON IN TITANIUM AND ZIRCONIUM USING ARGON MODERATOR.

Material	Sample Weight (g.)	Carbon (%)
C.P. Titanium .. .. .. (Medium carbon)	4 (+3g. Pb)	0·058 0·057 0·052
Titanium 371 Alloy .. .. (No. 1)	4 (+3g. Pb)	0·015 0·016
	1 (+2g. Pb)	0·018
C.P. Zirconium .. .. .. (No. 1)	3 (+3g. Bi/1g. Fe)	0·009 0·012 0·009
C.P. Zirconium* .. .. (No. 2)	3 (+3g. Bi/1g. Fe)	0·21 0·22 0·21
Zircaloy 2 .. .. (No. 1)	3 (+3g. Bi/1g. Fe)	0·010 0·012
	1 (+2g. Bi/1g. Fe)	0·012

* Melted using graphite electrode.

From observed changes in conductance, a calculated factor of 1·125 was obtained. These determinations were made over the conductance range 11,000 to 7,000 micromhos, and results showed no significant change in factor down to 8,000 micromhos, but below this value the factor increases slightly (Fig. 2). Similar results were obtained in tests using oxygen alone without argon moderator, and a furnace temperature of 1,250° C. without a flux, as recommended for the determination of carbon in steel.[5]

The conductimetric procedure with argon moderator was applied to a further B.C.S. standard steel (No. 237) and to samples of titanium and zirconium, using the appropriate flux. Results obtained (Table IV) were reproducible to ±0·001%.

Blank values (calculated on a 1 g. sample basis) on calcined boats containing 2 g. of lead were equivalent to 0·002% carbon, and in the presence of 2 g. of bismuth and 1 g. of iron were equivalent to 0·005% carbon.

TABLE IV.—CONDUCTIMETRIC CARBON DETERMINATIONS.

Material (1 g. samples)	Carbon (%)
B.C.S. Steel No. 237 .. .. (Certified carbon content 0·083%)	0·082 0·081 0·080 0·081
C.P. Titanium .. .. (Low carbon)	0·019 0·019 0·021 0·020 0·020 0·020 0·019
C.P. Titanium .. .. (Medium carbon)	0·053 0·055 0·055
371 Titanium Alloy .. .. (No. 1)	0·016 0·016 0·016
314A Titanium Alloy .. .. (No. 1)	0·023 0·023 0·025
318A Titanium Alloy .. .. (6% Al/4% V)	0·021 0·023 0·022
Titanium Sponge .. .. (No. 1)	0·008 0·008 0·007
C.P. Zirconium .. .. (No. 1)	0·013 0·011 0·012
C.P. Zirconium* .. .. (No. 2)	0·214 0·214 0·217
Zircaloy 2 .. .. (No. 2)	0·011 0·012 0·013

Standard deviation at 0·02% carbon level—0·0008.
2 g. of lead added to all titanium samples.
2 g. of bismuth and 1 g. of iron added to all zirconium-bearing samples.
* Melted using graphite electrode.

Gravimetric Method

Apparatus

The apparatus for the gravimetric method is shown schematically in Fig. 1*a* and descriptions read in the gas stream direction. As far as possible, connections should be made with P.V.C. tubing, and after the combustion tube the space between each component joined in this way must be at a minimum.

(1) Oxygen supply.*

(2) Argon supply.*

(3) Fine-control needle valves.

(4) Rotameter gauge (20–200 ml./min.).

(5) Preheating furnace, maintained at 450° C. and provided with a silica tube containing platinised asbestos.

(6) Tube containing, in order, Carbosorb and Anhydrone.

(7) Combustion tube closure (Ref. 5) fitted with small closure plug to obviate ingress of air during insertion of the sample.

(8) Refractory combustion tube, approx. 1¼ in. o.d. ×30 in. long.

(9) Refractory combustion boat, 4 in. ×1 in. ×½ in. (Alpolain No. 454).

(10) Electric furnace capable of maintaining a working temperature of 1,150° C.

(11) Purification tube containing in order, manganese dioxide (20–40 mesh), Anhydrone, anhydrous copper sulphate (on asbestos) and Anhydrone.

(12*a*) Absorption tube containing, in order, Carbosorb and Anhydrone.

(13*a*) Guard tube containing, in order, Anhydrone and Carbosorb.

(14*a*) Empty Arnold bulb, followed by an Arnold bulb containing sulphuric acid (sp. gr. 1·84).

Procedure

Adjust the furnace temperature to 1,150° C. (±10° C.) and regulate the oxygen flow through the apparatus to 80 ml./min. After 20 min. detach and weigh the absorption tube 12*a*; replace the tube and re-weigh at 15 min. intervals until successive weights remain reasonably constant, i.e., within 0·2 mg.

Wash the sample (*Note* 1), by decantation with trichloroethylene, then remove excess trichloroethylene by drying for 15 min. at 100° C. Transfer 3–4 g. to a previously calcined combustion boat (*Note* 2). In the analysis of titanium-bearing samples, add 3 g. of lead drillings (*Note* 3), and in the case of zirconium samples, 3 g. of bismuth drillings (*Note* 3) and 1 g. of iron drillings (B.C.S. No. 149).

Open the combustion tube closure, place the boat and contents just inside the tube and reseal the closure. Supply argon to the train at a rate of 80 ml./min. and simultaneously turn off the oxygen supply. After 5 min. remove the small closure-plug, move the boat into the centre of the hot-zone and replace the plug. In the case of titanium samples, turn off the argon and supply oxygen at 80 ml./min.; for zirconium samples, reduce the argon to 25 ml./min. and supply oxygen at 80 ml./min.—maintain this mixed flow for 5 min., then turn off the argon completely.

During oxidation of the sample, increase the flow of oxygen as required to maintain a steady flow of gas through 14*a* (about 3 bubbles/sec.). When oxidation is complete, usually after about 5 min., sweep out with oxygen at 80 ml./min. for 15 min., then re-weigh the absorption tube.

$$CO_2 \times 0{\cdot}2729 = C.$$

Notes

Note 1.—In the form of fine turnings, prepared, if possible, in the absence of a lubricant.

Note 2.—Combustion boats must be previously well calcined at not less than 1,000° C. and blank values, determined at frequent intervals on a calcined boat containing the appropriate flux. Periodic determinations using a standard titanium or zirconium sample or a standard reference steel serve to indicate the efficiency of the train.

Note 3.—The blank value on chemical lead or bismuth is reduced by melting the metal, heating for a few minutes, and cooling in a mould before drillings are taken.

Conductimetric Method

Apparatus

The apparatus for the conductimetric method is shown schematically in Fig. 1*b*. Components 1–11 are as listed in the apparatus for the gravimetric method; the remainder are as follows:—

(12*b*) Glass stopcock.

(13*b*) Arnold bulb—empty.

(14*b*) The following components are adequately detailed in Reference 5, and refer to the G.E.C. Conductimetric Unit—Cat. Nos. S.P. 1210 and 1220.
The conductimetric cell is connected to a measuring bridge with a vibration galvanometer and a 1,111 ohm four-decade resistance box.

(15*b*) Thermostatic unit, consisting of a combined heater and stirrer, with a mercury/toluol regulator and a separate controller.

(16*b*) Water-bath, 15 in. diameter ×10 in. deep, for use with the thermostatic unit. Water is circulated through a cooling-coil, immersed in the thermostat bath, when laboratory temperatures exceed 25° C.

(17*b*) Thermometer—graduated in tenths of a degree centigrade.

Reagents

Sodium Hydroxide Solution (1 g./litre)

Lissapol N Solution (1 : 50)—Dilute 1 ml. of Lissapol N with 50 ml. of distilled water.

Procedure

Filling the Cell (*Note* 1).

Remove the knurled screw from the base of the cell and raise the lid about 1 mm., thereby allowing used solution to drain (*Note* 2). Replace the screw and remove the filling plug from the lid. Place the cell on the pan of a rough balance and add sodium hydroxide solution

* Controlled at 5–10 lb./sq. in. from a cylinder provided with a safety regulator gauge (0–30 lb./sq. in.) and a mercury lute (water-sealed).

(1 g./litre) to balance two counter-poises—one 50g., the other equal in weight to the empty cell (*Note* 3). Add a few drops of the Lissapol N solution (*Note* 4). Replace the filling plug, place the cell in position in the thermostatically controlled water-bath (25° ± 0·02° C.), connect the cell to the combustion train, and the cell electrodes to one of the pair of bridge terminals.

Oxidation of the Sample.

Adjust the furnace temperature to 1,150° C. (± 10° C.) and regulate the oxygen flow through the apparatus to 50 ml./min. Wash and dry the sample, as in the gravimetric procedure, then transfer 1 g. of the fine turnings to a previously calcined combustion boat (*Note* 5). In the analysis of titanium samples, add 2 g. of lead drillings and in the case of zirconium add 2 g. of bismuth drillings and 1 g. of iron drillings (B.C.S. No. 149). Open the combustion tube closure, place the boat just inside the tube and reseal the closure. Increase the oxygen flow to 150 ml./min. for 5 min., then reduce it to 50 ml./min., and measure the conductance at 3 min. intervals until the bridge reading is constant. Turn on the argon supply at 50 ml./min. and simultaneously turn off the oxygen supply.

After 5 min., check the bridge reading, remove the small closure-plug, push the boat into the centre of the hot zone and replace the plug. Increase the argon flow momentarily in order to restart the flow of gas through the cell (*Note* 6). When bubbles are again flowing steadily through the cell, turn off the argon supply, then admit oxygen at the rate of 50 ml./min. Increase the flow of oxygen as required during oxidation of the sample. If very vigorous oxidation occurs, close stopcock 12*b* to prevent solution from being sucked out of the cell. When oxidation is complete, usually after about 5 min., adjust the oxygen flow to 50 ml./min. Determine the conductance after 15 min., and thereafter every 3 min., until the bridge reading is constant.

$$\text{Carbon (\%)} = \frac{\text{micromhos change} \times \text{factor}}{\text{sample weight (g.)} \times 10^4} \quad (\textit{Note}\ 7)$$

Use of Conductimetric Bridge.

Standardisation.—Connect the 1,111 ohm resistance box to the appropriate bridge terminals, and the cell to one of the pairs of terminals marked C1 to C4. Set the range switch to the low range, the capacity decade switches to zero, the rotary switch to the position marked "Int. Std.," and the dials of the resistance box to 1,000 ohms. Switch on the bridge and adjust the "Standardise" rheostat to give a zero reading on the galvanometer. Depress the sensitivity switch and adjust the rheostat more closely, if necessary (*Note* 8). The resistance box dials now read directly in micromhos of conductance, up to 11,110 micromhos. Once the bridge has been standardised, a repeat standardisation is rarely necessary except when the range of the bridge is changed.

Measuring Cell Conductance.—Turn the rotary switch to the appropriate position (C1 to C4). Obtain an approximate zero galvanometer reading by adjusting the first and second dials of the resistance box. Depress the sensitivity switch and reduce the galvanometer reading to as low a value as possible by adjusting the capacity decade switches. Keeping the sensitivity switch depressed, make a further adjustment of the resistance box dials and continue to adjust the capacity (*Note* 9) and resistance alternately, until a clearly defined hairline is seen on the galvanometer scale. The resistance box dials then indicate the conductance of the cell.

Notes

Note 1.—When not in use, leave the solution in the cell to prevent the electrodes drying out.

Note 2.—The electrode stem must only be removed from the cell when it is absolutely necessary to do so. Platinum black is likely to be removed from the electrode surfaces if the electrodes are removed frequently.

Note 3.—If the cell factor changes significantly (say, outside ± 0·005), the 50 g. counterpoise may be adjusted so as to alter the volume of solution used, thereby maintaining a reasonably constant factor. The cell counterpoise may also be adjusted if any alteration is made which affects the cell weight.

Note 4.—The volume of Lissapol N solution required is best found by trial, and is usually in the range 1–5 drops. Too little allows the bubbles to coalesce too early on their way up to the helix, leading to alternate slow and fast bubbling and erratic conductance readings; excess causes persistence of foam in the top part of the cell, with possible loss of solution through the gas exit tube.

Note 5.—Combustion boats must be previously well calcined at not less than 1,000° C.

Note 6.—Sudden flow of gas may cause bubbles to escape through the electrode chamber instead of round the helix. If this happens, the gas flow should be stopped and restarted when bubbles have cleared from the electrode chamber. It is impossible to obtain a steady conductance reading if bubbles remain in contact with one of the electrodes.

Note 7.—

$$\text{Factor} = \frac{\text{Carbon (\%)} \times \text{sample weight (g.)} \times 10^4}{\text{micromhos (change)}}$$

This factor is determined by repeated examination of a sample of known carbon content, e.g., a B.C.S. steel, using different parts of the bridge range. The actual factor found is plotted against the mean conductance, (i.e., the average of the two conductance readings before and after the oxidation).

Note 8.—Zero current of the galvanometer is indicated by the patch of light on the scale contracting to a circle with a sharply defined line across the centre; the actual position of the line on the scale is unimportant.

Note 9.—The value of the capacity used has no influence on the magnitude of the conductance reading; it only affects the sharpness of the zero.

Conclusions

Carbon can be satisfactorily determined in titanium, zirconium and their alloys, either gravimetrically or conductimetrically, by procedures involving the use of argon to moderate the otherwise vigorous oxidation reaction. A mixed flux of bismuth and iron is recommended with fine turnings of zirconium and Zircaloys, but lead is necessary to ensure complete oxidation of titanium samples.

The gravimetric method is suitable for application where carbon contents of the order 0·02% to 0·2% are to be determined, and is recommended for use on a routine basis. Its precision, with sample weights up to

about 4 g., is about 0·005%. Using a smaller sample weight, the method can be extended to the determination of larger amounts of carbon.

The conductimetric method has a precision of ±0·001% and is a suitable alternative procedure, particularly in the determination of carbon below about 0·05% where the weight of sample available does not exceed about 1 g. It is recommended as a standard reference method and for use on a routine basis where only a small amount of sample is available.

Acknowledgments

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Investigations on Colorimetric Methods of Metallurgical Analysis

Part VI—Estimation of Silicon in Cast Iron Using the Duboscq Type of Colorimeter

By G. V. L. N. Murty, M.Sc., D.Sc., F.R.I.C., F.A.Sc.

Department of Chemical Laboratories, The Tata Iron and Steel Co., Ltd., Jamshedpur, India.

A simple procedure has been described for the estimation of silicon in pig iron which compares very favourably, in regard to accuracy attainable, with the standard gravimetric methods. This new procedure has the striking advantage of reducing the time of analysis to 15 minutes, a factor which is of considerable importance in steel works analysis.

IN any integrated steel works, speedy and accurate analysis of pig iron from each blast furnace cast is of considerable importance, as it helps the maintenance of satisfactory conditions at the blast furnaces and steel melting shops, and facilitates proper transport of the hot metal to the different consuming units. Silicon, sulphur and manganese are the elements usually determined cast by cast, with phosphorus as one of the elements determined on an average sample from a number of casts. The determination of silicon, as carried out by the conventional gravimetric procedure, takes rather a long time, and investigations undertaken with a view to effecting an improvement in this respect have resulted in the introduction of a colorimetric procedure which has been used successfully for works control for the last few years.

An examination of the literature on the subject of silicon determination showed that colorimetric methods using the Pulfrich photometer in combination with a mercury arc light source had been tried by several workers with varying degrees of success. The earlier methods worked out by Pinsl,[1] Weihrich and Schwarz,[2] Rozental and Campbell,[3] and Hill[4] depend on the formation of a yellow heteropolar complex of silicate and molybdate ions,[5] the colour intensity of which in weak acid solution gives a measure of the silicon content. Though at first sight these methods appeared to offer great possibilities, a thorough examination showed that, owing to a number of small details that have to be taken into account, they are not convenient for routine control work involving a large number of samples. The difficulties of colour matching are also enhanced when comparisons are made in artificial light, which is inevitable in a continuously operating steel plant. Hence, methods based on the development and comparison of blue colours have begun to commend themselves.

Absorptiometric methods, based on the molybdenum

TABLE I.—INFLUENCE OF TIME INTERVALS AFTER THE ADDITION OF STANNOUS CHLORIDE ON THE ABSORPTIOMETRIC COLOUR VALUES (TIME AFTER MOLYBDATE ADDITION IS 2 MINUTES IN ALL CASES)

Number	Silicon (gravimetric) (%)	Colour Value with Time Interval after adding Stannous Chloride of					
		30 sec.	1 min.	2 min.	15 min.	30 min	1 hr.
1	0·80	15·0	29·0	29·0	29·3	28·5	24·0
2	1·05	24·0	38·0	38·0	38·0	35·0	27·0
3	1·21	29·0	45·2	45·5	45·5	42·0	32·0
4	1·30	34·5	47·0	47·0	47·0	43·5	36·0
5	1·45	43·0	54·0	54·2	54·5	48·5	39·5
6	1·90	48·5	65·0	65·0	65·5	58·0	45·0

TABLE II.—INFLUENCE OF TIME INTERVALS AFTER THE ADDITION OF AMMONIUM MOLYBDATE ON THE ABSORPTIOMETRIC COLOUR VALUES.

Number	Silicon (gravimetric) (%)	Colour Value with Time Interval after Adding Ammonium Molybdate of						
		Zero (< 5 sec.)	15 sec.	30 sec.	45 sec.	1 min.	2 min.	5–10 min.
1	0·80	13·5	23·0	26·5	28·0	29·0	29·0	29·0
2	1·05	17·0	29·5	35·0	36·5	38·0	38·0	38·0
3	1·21	20·3	34·5	40·0	43·7	45·0	45·2	45·2
4	1·30	22·0	37·5	43·5	45·5	47·0	47·0	47·0
5	1·45	22·8	39·0	45·0	49·0	54·0	54·0	54·0
6	1·90	22·8	43·3	53·5	57·7	65·0	65·0	65·0

TABLE III.—INFLUENCE OF TIME INTERVALS AFTER THE ADDITION OF 25% SULPHURIC ACID ON THE ABSORPTIOMETRIC COLOUR VALUES

Number	Silicon (gravimetric) (%)	Colour Values with Time Interval after adding 25% Sulphuric Acid of		Silicon (%) Determined by the Visual Procedure with Time Interval after adding 25% Sulphuric Acid of	
		Immediate (<5 sec.)	1–2 min.	Immediate (<5 sec.)	1–2 min.
1	0·80	28·0	28·0	0·82	0·80
2	1·05	38·5	38·0	1·00	1·05
3	1·21	44·5	45·0	1·22	1·20
4	1·30	47·0	47·3	1·32	1·35
5	1·45	54·0	54·0	1·50	1·50
6	1·90	65·0	65·3	1·80	1·80

blue colour obtained by reduction of the heteropolar complexes referred to above, were worked out by Vaughan[6] and others.[7-9] These procedures are rather attractive because the colour contrast is striking and the stability of the blue colour is fairly satisfactory. However, they require not less than 40–45 minutes for completion of the silicon determination. The systematic investigations we carried out for effecting the maximum saving of time may be reviewed briefly as follows.

To begin with, a number of experiments were conducted to see how far the modified method of silicon determination in steel worked out in our laboratories[10] would be applicable to cast iron if a smaller sample weight were taken. Though this showed some promise, the need for further speeding up was keenly felt. Work was therefore directed to an exploration of the possibilities of saving as much time as possible at each stage of the analytical operations, which resulted finally in the evolution of a satisfactory procedure requiring only 15 minutes for a single silicon determination.

Time Intervals after adding Stannous Chloride

Experiments in which the time intervals after adding stannous chloride were varied, the rest of the procedure remaining the same, have shown that the maximum depth of blue colour can be obtained in 1 minute, after which it remains constant for at least 15 minutes. Slight fading commences after 30 minutes and becomes more pronounced in an hour. Drum differences in the Spekker photo-electric absorptiometer, which are described as colour values in the present paper, were taken as indications of the depth of colour at various stages. The results obtained in this connection are set out in Table I.

Time Intervals after adding Ammonium Molybdate

Efforts to speed up the analysis by adding ammonium molybdate and then quickly adding 25% sulphuric acid without waiting for a definite period have yielded low and varying colour intensities. Several experiments were therefore performed to study the influence of these factors on the intensities and stability of the blue colour. The periods of waiting studies were : (1) none, i.e., less than 5 seconds ; (2) 15 seconds ; (3) 30 seconds ; (4) 45 seconds ; (5) 1 minute ; (6) 2 minutes ; and (7) 5–10 minutes. The results presented in Table II clearly show that the time interval after the ammonium molybdate addition is a very important factor influencing the depth of the final colour. The colour values continue increasing until 1 minute interval, after which they remain constant. It may also be seen that the differences in the colour values between those recorded in the 1 minute interval column and those for shorter periods are not constant. It has, therefore, been considered safe to wait for at least a minute after the ammonium molybdate addition.

TABLE IV.—INFLUENCE OF TEMPERATURE ON THE SILICON CONTENTS DETERMINED

Number	Silicon (gravimetric) (%)	Silicon (%) Determined by the Visual Procedure	
		Sample Solution used Immediately	Sample Solution cooled to Room temperature
1	0·80	0·85	0·85
2	1·05	1·00	1·00
3	1·21	1·20	1·23
4	1·30	1·35	1·30
5	1·45	1·50	1·47
6	1·90	1·80	1·80

Time Intervals after adding 25% Sulphuric Acid

The investigation on this factor has shown that there is no harm in adding stannous chloride immediately after the addition of 25% sulphuric acid (*vide* Table III).

Other Factors

Instead of dissolving the samples in beakers, and then transferring the solutions to measuring flasks, it was found advantageous to dissolve them in the latter. The undissolved graphitic carbon may be allowed to remain in the flask, and no effort need be made to cool the solution to room temperature (*vide* Table IV).

Procedure

Based on the investigations described in the preceding section, the following procedure has been established.

Reagents

Sulphuric Acid A—10% by volume.

Solvent Mixture—A solution of 7% ammonium persulphate in sulphuric acid A. (To be prepared once in two days).

Sulphuric Acid B—25% by volume.

Stannous Chloride—5 g. pure crystals dissolved in 6–8 ml. conc. hydrochloric acid and made up to 500 ml. (This has to be freshly prepared each day).

Ammonium Molybdate—25 g. pure crystals, dissolved in boiling water which, on cooling, is made up to 500 ml.

Potassium Permanganate—2%.

Sulphurous Acid.

Determination

Weigh out 0·2 g. of the cast iron sample (after the usual magnetic separation) into a funnel kept on the mouth of a 250 ml. measuring flask, and wash it down completely by adding 35 ml. of the solvent mixture. The funnel is kept rotating when the solvent mixture is being added. Remove the funnel, add 6–10 drops of potassium permanganate solution to the measuring flask through a dropping bottle and heat to boiling for 5 minutes on a hot-plate. During these 5 minutes the following arrangements should be made for subsequent operations :

(*i*) Keep two beakers marked " standard " and " sample " near the colorimeter and fill them both with 50 ml. of distilled water.

(*ii*) Pipette out 20 ml. of the standard cast solution* into the beaker marked " standard."

(*iii*) Keep three measuring cylinders near each beaker at convenient positions.

* The standard cast solution is prepared by taking a cast containing 1·3% silicon and subjecting it to the same process as above, making the solution up to 250 ml. after heating. Large volumes of the stock solution may be prepared by proportionately increasing the quantities of the reagents. Investigations so far carried out have shown that the standard stock solution undergoes no change for as long as a month after its preparation.

TABLE V.—COMPARISON OF RESULTS BY THE NEW RAPID AND GRAVIMETRIC METHODS

Number	New Rapid Method (Silicon %)	Gravimetric Method (Silicon %)
1	0·85	0·84
2	1·00	1·03
3	1·10	1·14
4	1·23	1·24
5	1·30	1·32
6	1·40	1·40
7	1·54	1·50
8	1·66	1·66
9	1·74	1·75
10	1·82	1·79
11	1·98	2·00

(*iv*) Into the first one in each case pour 10 ml. of ammonium molybdate solution.

(*v*) Into the second pour 20 ml. of sulphuric acid B.

(*vi*) Into the third pour 10 ml. of stannous chloride solution.

At the end of the 5 minutes referred to above, add a few drops of sulphurous acid to clear any brown precipitate present, and remove the measuring flask from the hot-plate. Make up the solution to 250 ml.; cooling the solution or filtering the undissolved graphitic carbon is not necessary. Shake well three or four times to ensure uniform mixing, and pipette out 20 ml. of this solution into the beaker marked " sample."

To the two beakers add simultaneously the ammonium molybdate solution measured in the cylinders (*iv*). Wait for 1 minute and then add simultaneously the measured amounts of sulphuric acid B (*v*), followed by the stannous chloride solution (*vi*). Wait for 1 minute, by which time the faint blue colour obtained immediately after the addition of stannous chloride intensifies.

Fill the right hand cup of the Duboscq colorimeter with the coloured solution from the beaker marked " standard " and the left hand cup with the contents of the other beaker. Fix the left hand cup at the division marked 1·3, and adjust the right hand one so that the two halves of the colorimeter field match when viewed through a red filter kept on the eyepiece. (A Spekker filter is used for this purpose, and an Ilford red filter can also be used). Note the division corresponding to the right hand cup. Fill the left hand cup, after washing and rinsing it and the plunger, with the standard blue solution and, keeping it at the division 1·3, match with the standard on the right hand side. Usually the right hand side shows a value differing slightly from 1·3, which should indeed be the ideal value. This difference gives the correction to be applied to the value noted earlier. If the difference is positive, the correction should be negative, and vice-versa. The corrected value gives directly the percentage silicon in the sample.

Experiments carried out to check the accuracy attainable by this 15 minutes method have shown that it compares very favourably with the rigidly controlled gravimetric procedure. (*vide* Table V). Furthermore, in routine laboratory work, a time schedule may be fixed for various operations, so as to fit them in during the intervals available in the sulphur determination, with the result that the same chemist can deal simultaneously with the determination of sulphur, silicon and manganese.

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International Cybernetics Congress

THE International Association for Cybernetics is organizing the Second International Congress on Cybernetics in Namur (Belgium), from September 3rd to 10th. Its purpose is to bring together people having common interest in cybernetics, thus continuing the work of the 1956 Congress, which was attended by 800 participants from 22 countries. Subjects to be dealt with at the Congress will include: (1) information (information theory, computing machinery, etc.); (2) automatic machinery (the application of cybernetics to machines); (3) automation (the use of automatic machinery in industry and office work); (4) the economic and social effects of automation; (5) cybernetics and the social sciences; and (6) cybernetics and biology. Further particulars can be obtained from the Secretariat of the International Association for Cybernetics, 13, rue Basse Marcelle, Namur (Belgium).

Honeywell Changes

HONEYWELL-BROWN, LTD., changed its name to Honeywell Controls, Ltd., at the beginning of June. At the same time, all Head Office departments and the London Branch Office moved from Perivale to a new building at Ruislip Road East, Greenford, Middlesex (Tel.: Waxlow 2333). The new name identifies the Company with its range of products and lines up with the names adopted by most overseas affiliates of the Company. The new building, which incorporates many modern aids to operating efficiency, puts all marketing functions—sales and service engineering, training school, export activities—and their executive direction, under one roof.

Mullard Semiconductor Division

THE rapid expansion of the development, production and application of all types of semiconductor devices has led Mullard, Ltd., to establish a separate product group to be known as the Semiconductor Division, which will co-ordinate all Mullard product activities in the semiconductor field. Within the division two departments will be established, dealing with commercial and technical aspects, respectively.

Evershed & Vignoles' Scottish Office

AFTER a long association with James Ferguson & Munro, Ltd., Evershed & Vignoles, Ltd., have decided, as a matter of policy, to terminate the agency and have direct representation in Scotland. The Scottish area office is at 13 Rutland Street, Edinburgh, 1 (Tel.: Fountainbridge 3058), and is under the management of Mr. R. M. Wardrop.